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THE ELEMENTS

OF

ELECTRIC LIGHTING,

INCLUDING

ELECTRIC GENERATION, MEASUREMENT, STORAGE,
AND DISTRIBUTION.

BY

PHILIP ATKINSON, A.M., PH.D.,

AUTHOR OF "ELEMENTS OF STATIC ELECTRICITY," "THE ELEMENTS OF DYNAMIC
ELECTRICITY AND MAGNETISM," "THE ELECTRIC TRANSFORMATION OF POWER," "ELECTRICITY FOR EVERYBODY."

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INTRODUCTION.

THE object of this volume is to meet the demand for a complete, comprehensive treatise, setting forth the various facts pertaining to electric lighting in plain language, devoid of technicality and perplexing mathematical formulæ, from which business men, mechanics, and those who have the care and management of dynamos and lamps, as well as general readers, may gain a knowledge of the principles and construction of the apparatus by which this light is produced, and of the nature of that invisible, intangible agency which is its prime cause. It is also designed as a convenient handbook for the electrical engineer, from which he may refresh his memory in regard to the apparatus described and its use, or gain a hint as to the nature of electricity as developed in its practical application.

As the storage battery has become an important auxiliary in electric lighting, a full description of its construction, principles, and application has been given, and also of the inductive, alternating current system, which has recently been so largely developed.

Among other sources of information, the writer has freely consulted the excellent works of Thompson, Schellen, Maier, Gordon, Niaudet, and Gladstone and Tribe, and has availed himself of the advantage of various cuts used by them, illustrating principles and apparatus. He also takes great pleasure in acknowledging his obligations to the various electric light companies whose apparatus is described, for highly valuable practical information and the free use of numerous cuts; also to the various electric journals for similar information, especially to the "Electrical Engineer," "Electrical World," and "Western Electrician."

PHILIP ATKINSON.

CHICAGO, Aug. 16, 1888.

Introductory Note to the Ninth Edition.

IMPORTANT changes made in the construction of dynamos within the last five years have rendered a complete and thorough revision of chapters III and IV necessary; since most of the dynamos described in the first edition have gone out of use, and new dynamos, chiefly of the multipolar type, and designed for heavier work, have taken their place. The latter are here described in full, instead of the former.

It has also been found desirable to reverse the relative positions of these two chapters, placing the one on "Direct Current Dynamos" directly after chapter II, in which the principles of the dynamo are illustrated by dynamos of this type.

Two new kinds of storage batteries have been described, instead of two which have gone out of use. A brief description of vacuum tube lighting has also been introduced, and important additions made to the description of arc lamps, transformers, and electric units; and thirty-one new illustrations take the place of the same number of old ones.

These changes and additions comprehend all that are strictly required to bring the information furnished in this book fully up to date.

PHILIP ATKINSON.

CHICAGO, Oct. 1, 1897.

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THE ELEMENTS
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ELECTRIC LIGHTING.

CHAPTER I.

ELECTRICITY A MODE OF MOLECULAR MOTION.

INTRODUCTORY NOTE. — To understand clearly what electricity is capable of doing, it is important to ascertain, if possible, what it is; and while it can not perhaps be shown with absolute certainty that the long-sought solution of this problem has been found, yet the proofs from numerous sources converge chiefly in the direction indicated in this chapter; and in all the various phenomena pertaining to electric lighting, the theory here set forth is found to be closely in accordance with the facts; hence it has been deemed important to make it the introduction to the phenomena to be described hereafter.

THE elementary components of the natural universe are matter and energy. Matter in the abstract is inert, it can move or act only as actuated by energy, and energy in the abstract is incapable of movement or action except through the medium of matter. But we have no actual knowledge of either in the abstract, nor can we separate them, and all our conceptions of them in this respect are theoretical. All matter, even when apparently inert, is under the influence of energy, both in respect to its mass and its molecules. The apparent inertness of the mass is only relative. A steel rail, resting in its place on the track, is relatively inert with respect to its immediate surroundings, but as a part of the earth it partakes of the earth's motion as a mass; and close observation and measurement show that its dimensions are subject to continual variation with continual change of temperature — the result of expansion and contraction, — which proves that its molecules are in continual motion. The same is true of the column of mercury or alcohol in the thermometer, in which change of dimension is more apparent.

All matter is subject to change of dimension with change of temperature, but not all in the same degree. In many kinds, as baked wood, bone and ivory, it is almost imperceptible, requiring delicate instruments to detect it; while in others, as gas, vapor, and mercury, it is more prominent; so that if change of dimension be accepted as proof of molecular motion, it must be admitted that such motion is a constant, natural condition of all matter, since an absolutely stationary temperature may be regarded as a practical impossibility. Hence, the absolute immobility of matter, either in its mass or its molecules, must be regarded as a purely mental conception, having no existence as an actual fact.

But even if the maintenance of an absolutely stationary temperature could be demonstrated as a possibility, such demonstration would not disprove the continuous molecular motion of matter, since it has been fully demonstrated that heat itself is a mode of motion; so that to admit the constancy of heat in matter is to admit the constancy of molecular motion.

It is not important to adduce the proofs on which this theory rests. It is sufficient to state that it is maintained by the highest scientific authority, and accepted as a fundamental doctrine of modern science.

Common observation shows that nothing is so hot that it can not become hotter, or so cold that it can not become colder, heat and cold being merely convenient relative terms to express different degrees of temperature. Steam generated under a pressure of several atmospheres is much hotter than when generated under a pressure of one atmosphere. Cold iron is relatively warm as compared with colder iron. Even ice itself possesses a certain degree of heat.

The theory of sound, as an undulatory movement of the air, is too well established to require the presentation of proof; and the theory of light, as another form of undulatory movement, has also been accepted as a well-established doctrine. But in regard to the nature of electricity scientific opinion has been greatly divided, and no theory yet proposed has been so free from objection as to be generally accepted. But electric development during the last ten years has done much toward the settlement of this question; and the theories and opinions of the great electricians of the period immediately previous are yielding to the steady pressure of recent investigation, just as their investigations modified or displaced former theories and opinions.

Observation shows that electricity may be developed in every kind of matter; from which we may reasonably infer that it is a universal property of matter in the same sense as heat. In proof of this, we find that it may be promptly developed in the numerous class of bodies known as non-conductors by means of friction, and in the class known as conductors, which embraces all other bodies, by the same means, if they are first properly insulated. As an example of the latter class, we may select a brass rod; let it be insulated and subjected to friction from another insulated body, and electricity is rapidly developed, as shown by attraction, and by the spark and snap. That this electricity is developed in the rod itself, and not derived from the body by which the friction is produced, is proved by using a metal friction-brush, or metal in any form by which a light contact is obtained. The Varley and Töpler electric machines are examples of this. In the Armstrong hydro-electric machine we have a very notable instance of electricity generated by the friction of condensed steam, emitted through metal pipes tipped with wood. From these, and numerous other instances which might be adduced, we may conclude that electricity can be developed in all bodies by friction; its development in conductors, when insulated, being equally as practicable as in non-conductors.

The generation of heat by friction is coincident with that of electricity, and the heat continues to increase long after the electric development has attained its maximum. If the friction be sufficiently increased in the case of a solid body, as a metal, light is developed, the metal becoming incandescent. Thus, by the agency of friction, certain phenomena are produced, the first of which we call electricity, the second heat, and the third light. The last two we designate as modes of motion. Why not the first also? The friction is a result of mechanical energy acting through matter; the energy in this form disappears, and is reproduced as electricity, heat, and light. Each of these then is a different manifestation of energy acting through matter as its medium.

Since these manifestations are different, it is evident that each must have its own peculiar form of molecular motion; that the electric movement, which becomes prominent first, is the most easily and rapidly developed, and essentially different from the heat movement, which, though coincident with it, is developed more slowly; while light is not produced till the movement has assumed great intensity, the light changing from red to white as the intensity increases.

In the battery we have electricity produced by chemical reaction, and heat also as a coincident result. The chemical reaction is itself a mode of atomic and molecular motion by which atoms and molecules interchange and form new combinations; and since the incidental heat is admitted to be a mode of motion, we may reasonably infer that the more prominent electricity is another mode of motion; the energy disappearing in the chemical mode, reappearing in the heat and electric modes —molecular motion in one form being transmuted into molecular motion in the other two forms.

In the dynamo we have electricity generated by mechanical action combined with magnetic, electricity and magnetism reciprocally producing each other. Magnetism is admitted to be the result of a certain molecular arrangement in the substance of the magnet; and in the soft iron of the electro-magnets of the dynamo this molecular arrangement undergoes constant disturbance, producing a series of momentary electric currents with such rapidity as to maintain an apparently constant electric action. Hence we must infer that these magnets are in a constant state of intense molecular motion; and since magnetism and electricity are always coexistent and reciprocal, we are warranted in the conclusion that they are of the same nature, — *sui generis*, — and that if one is a mode of molecular motion the other must be. And this theory gains additional strength from the fact that here again we find heat generated as an incidental result, to such an extent that special arrangements are required to keep the dynamo from being injured by overheating.

In the thermopile we have electricity generated by the direct agency of heat; and in order to create a difference of electric potential, which is the principle upon which every electric generator is based, a difference of heat potential must be created. This is accomplished by the use of two metals, usually bismuth and antimony, having different conductivities for heat and electricity. Bars of each are smelted together at the ends, and arranged in compact form in an alternating series, in such a manner that one set of junctions can be heated while the alternate opposite set is cooled. The electric current flows across each heated junction from bismuth to antimony, and across each cooled junction from antimony to bismuth, so that at each junction it receives a fresh impulse in the same general direction, since the heated and cooled junctions alternate. The specific capacity of bismuth for heat is 0.030, and that of antimony, 0.051, that of water being unity; and the temperature of each, when heated or cooled from the same source, varies inversely as *this* specific capacity; hence, at the heated junctions the temperature of the bismuth rises above that of the antimony, and at the cooled junctions falls below it; and as the heat movement as well as the electric movement is from higher to lower potential, we find here an exact correspondence in the movement of each.

But there is also a difference in the molecular constitution of the two metals, as indicated by their crystalline structure, bismuth crystallizing in one form while antimony crystallizes in another; and the greater the difference in this respect, as well as in conductivity for heat and electricity, between these or any other two metals, the more energetic the thermoelectric action. Indeed this difference in crystalline structure, and hence in molecular constitution, is undoubtedly the cause of the difference in conductivity; the difference in electric and heat potentials corresponding, as shown, to the difference in electric and heat conductivities.

But we have also in this instrument an instance of the reciprocal action between heat and electricity. If instead of heating and cooling alternate junctions to generate electricity, an electric current is passed through from an external source, the junctions become heated or cooled according to the direction of the current. A current passed through a bismuth-antimony pair from antimony to bismuth heats the junction, while if passed through from bismuth to antimony the junction is cooled. According to the doctrine that heat is a mode of motion, the heating is an increase in the intensity of motion, and the cooling a decrease of that intensity; and in this experiment the reduction of temperature has been carried to such an extent that water has been frozen in cavities made in the metals. It will also be perceived that the same correspondence of movement between heat and electricity exists in the reciprocal action by which heat is generated, as in the direct action by which electricity is generated.

The generation of electricity by light, or, as Dr. Werner Siemens terms it, "the direct conversion of the energy of light into electric energy," has received the attention of leading electricians, and led to the invention of instruments for that purpose; and, although the invention is still confined to the laboratory, enough is known to demonstrate the possibility of such conversion, and hence to establish the fact of such an intimate relation between these two different manifestations of energy as to indicate the probability of a similar nature. The means employed is, in some respects, not unlike that already described for the generation of electricity by heat, — a combination ot metals differing in molecular construction and conductivity. But in this case metal plates are used; and selenium seems to have the preference, combined with gold and some base metal.

The accepted doctrine of light as a mode of motion is too well known to require elucidation here; but the nature of the instrument above referred to, and the requirement of metals for its construction differing in molecular constitution, indicate that the mode of motion known as light is changed by contact with the metals into the mode of motion known as electricity, either by this contact generating the resulting mode of motion in the metals themselves, or in some medium permeating their structure.

The action then in all these modes of generation is both direct and reciprocal. Heat produces electricity, and electricity produces heat; magnetism produces electricity, and electricity magnetism; light produces electricity, and electricity light. There is also reciprocal action between mechanical motion and electricity; but the connection is not so close and intimate as between the different forms of molecular motion, in which proof in regard to the nature of one becomes proof in regard to the nature of the other.

Thus far we have confined our attention to electric generation, but electric transmission is of equal importance in elucidating our subject; for if we could satisfactorily determine how electricity is transmitted, we should be in a fair way to determine what it is.

Assuming the truth of our original proposition, that energy is inseparable from matter, and that electricity is one of the forms in which energy manifests itself, a medium, consisting of matter in some form, is essential to its transmission. On this point there are two theories; one, that energy uses the different forms of tangible matter as its medium; the other, that all tangible matter — solid, liquid, and gaseous — is permeated by a certain intangible fluid known as ether, which constitutes the medium for electric transmission. The former theory assumes that electric transmission is by vibrations of the tangible matter itself; the latter, that it is by vibrations of the intangible ether. As both theories assume a mode of motion, and are in this respect equally well adapted to our purpose, it is unnecessary to enter into the discussion of their respective merits, further than to say, that the existence of ether has never been demonstrated, that the ether theory is unsupported except by inferential proof, and that the transmission of electric energy by the vibratory motion of tangible matter is the more reasonable theory of the two, and far more susceptible of demonstration.

The theory of the universal ether was originally invented to meet the necessity of a medium for the transmission of light through the interplanetary spaces, where it has been supposed that air can not exist, and its adaptation to electricity is of more recent origin. But the theory of the existence of a universal atmosphere, like that of the earth, has strong support, though, in the interplanetary spaces, it must be almost as impalpable as the supposed ether itself.

The two important factors in electric transmission are conductivity and resistance; one of which is always in the inverse ratio of the other, and the relative proportions of each in every substance constitute the difference between the conductor and the non-conductor. We may assume that electric transmission depends on molecular structure, that in good conductors this structure is such as to facilitate transmission, and in inferior conductors to retard it, while the structure of non-conductors is such as almost wholly to prevent it; and we may suppose, that in a good conductor the molecules lie in parallel lines, and that the electric energy causes each molecule to impinge on the next contiguous one, producing an undulation which runs through the conductor for perhaps a thousand miles in an instant; but that in the inferior conductor, or the non-conductor, the molecular arrangement is more or less irregular, requiring a wrenching or twisting of the molecules to bring them into position. It is evident, that in the latter case far greater energy is required to produce the same result, and that this series of wrenchings and twistings must result in the coincident development of that other mode of motion which we term heat. So that while in a good conductor, as a copper wire, electric transmission is easily effected, and the development of heat very slight, in an inferior conductor, as a platinum wire or a carbon filament, the heat development rises to incandescence. These results indicate that the transmission of electric energy is by molecular motion, as assumed, or rather that this mode of motion by which this energy manifests itself is that which we term electricity.

According to the old theory of thunder and lightning, the passage of electric fluid through the air produces the flash, and the thunder is a result of the air displacement and collapse. This theory is evidently incompatible with the theory of electric energy using the air as its medium. According to the latter view, there is no passage of electric matter through the air, and consequently no displacement except that resulting from the incidental development of heat. The electric discharge takes place along a narrow line, often three to five miles or more in length. The air along this line becomes incandescent, and is expanded by the intense heat; but the partial vacuum thus created is confined to this narrow line, and the collapse is quite insufficient to account for the terrific peal of thunder which often accompanies the flash. But the intense vibration occurring throughout this long line in an infinitesimal moment of time must produce the thunder-peal in strict accordance with the well-known laws of sound. It is possible that the succession of vibrations following the discharge, and set in motion by it, produces the rumble often heard, but the one tremendous vibration is the first immediate result of the discharge.

Comparing the results of thunder and lightning with those of explosions of gunpowder and dynamite, we find a very essential difference. In the explosion there is a displacement of a great volume of air, not confined to a single line, but diffused over a large space; and the results of the sudden expansion and collapse are often the breaking of glass and the destruction of buildings in the immediate vicinity, the effect of the air movement being often felt at a distance too great for the sound to be audible. But the electric discharge takes place over our dwellings, or between earth and cloud in our immediate vicinity, accompanied by the terrific thunder-peal, often far exceeding the sound of the loudest explosion, and the only perceptible effect is a slight tremor such as should follow from the vibratory movement assumed in our hypothesis. Hence we conclude that the transmission of electric energy in this case is by a vibratory motion; or, as before, that this mode of motion, so produced, is electricity.

All electric action is an exhibition of energy, whether it be in the movement of a pith ball, in the flash of the electric spark, in the brilliancy of the arc light or the softer radiance of the incandescent, in the deposition of metal by electrolysis, the click of the telegraph, the speech-producing movement in the telephone, the propelling of cars on a railway, or in the lightning's flash rending the oak. It produces chemical decomposition, mechanical motion, light and heat. It inflicts pain, destroys life, soothes suffering, heals disease. All these varied phenomena are different manifestations of energy.

Since electricity, then, is a product of energy and a producer of energy, it is manifestly closely allied to energy. But high electric authority says, "Whatever electricity is, it is not energy." This is true if we speak of energy in the abstract. But in this sense neither is heat energy, nor light, gravity, or mechanical motion. Energy in the abstract is a mere mental conception having no actual existence; it must act through matter as its medium, and in this concrete sense there can be no more objection to regarding electricity as one of the forms in which energy manifests itself than in regarding heat, light, or sound in that sense; and since every manifestation of energy is by means of motion, the conclusion seems inevitable that *electricity is a mode of molecular motion.*

CHAPTER II.

PRINCIPLES OF THE DYNAMO.

THE requisites for the production of the electric light are an electric generator, an electric lamp, and a conductor connecting the generator and lamp.

The generator must be capable of producing continuous, steady electric action of sufficient energy for the required work. It may be either an ordinary battery or a dynamo.

From the beginning of the present century until about 1867 the battery was the only known generator capable of producing the electric light; the electric machine, though capable of powerful effects, being incapable of producing a continuous electric current. All batteries are not equally well adapted to this purpose: the Daniell, Leclanché, and many others, which are adapted to various other kinds of electric work, are not suitable for the production of the electric light. The Bunsen battery can be used; and if a light of short duration only is required, as in surgical examinations or theatrical effects, any good carbon-zinc battery will answer the purpose. But for a strong light of several hours' duration, the Grove battery is superior to all others, 40 to 50 Grove cells being capable of producing such a light for two or three hours. From these facts it is easy to see why electric lighting, though known as *early* as 1800, was merely a laboratory experiment until about 1867; the great expense and labor of renewing the fluid in 40 or 50 Grove cells once in two or three hours being alone sufficient to render the ordinary use of the light obtained in this way impracticable, while the noxious fumes from such a battery make its use for this purpose practically prohibitory.

THE DYNAMO.—In 1867 the previous inventions of several leading electricians culminated in the production of the dynamo; and the problem of general electric lighting on an economical basis received a practical solution, since electricity could now be generated by mechanical power at far less cost and in far greater quantity than was possible or practicable by the chemical process of the battery.

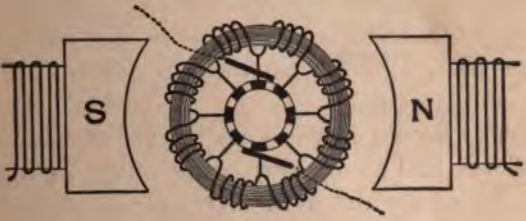

Fig. 1.

Without entering into perplexing details, the essential parts of the dynamo, and its mode of action, may be briefly described. These parts are the armature, the field-magnets, the commutator, and the brushes.

THE ARMATURE.—The armature, in its usual form, consists of a number of coils of copper wire, wound on an iron ring, which is mounted on an axis and revolved between the poles of the field-magnets, as shown in Fig. 1. The iron ring or core of the armature may consist of a number of iron wire rings, or of flat rings stamped out of thin sheet-iron, and placed vertically side by side, or of thin iron hoops laid over each other. These should be of the best soft iron, and electrically insulated from each other by varnish, asbestos, mica, or other suitable insulator. Solid iron cores are objectionable, chiefly on account of becoming heated; and the cores here described are greatly improved by having an open structure, so far as practicable, for the free circulation of air, by which the heating is greatly reduced. The insulation and composite structure, described above, are also important in giving the electric current its proper normal direction, and preventing the formation of the electric eddies, known as Foucault currents, which waste the energy and generate heat, a fault to which solid cores are especially liable.

The coils shown in the cuts are reduced to a few turns of wire and an open structure, but those in actual use consist of a number of layers closely wound like thread on a spool. The wire should be as large, and the number of turns in each coil as numerous, as practical convenience will admit; the resistance of the wire to the passage of the electric current, and the consequent heating, being reduced with increase of size, while the electric energy increases with the number of turns; each turn adding its quota to the current generated, provided the amount of copper is thereby increased; but there is no increase of energy by the mere substitution of fine wire for the same amount of copper in coarse wire. The wire in the coils, and in every part of the dynamo and its connections through which an electric current flows, must be covered with some good insulating material, which will confine the current to the direction in which it is designed to flow, and prevent its escape from one turn to another, or to any object with which the wire may come in contact.

THE COMMUTATOR. — Figs. 1 and 2 show that the ends of the coils connect with cylindric segments at the axis of the armature: these constitute the commutator, whose use will be fully explained hereafter. Its segments are of copper or some other suitable metal, as phosphor-bronze, or gun-metal; the requisites being that the metal must be a good conductor, and not liable to heating or corrosion. They are attached to the axis, and insulated from it and from each other, and of the

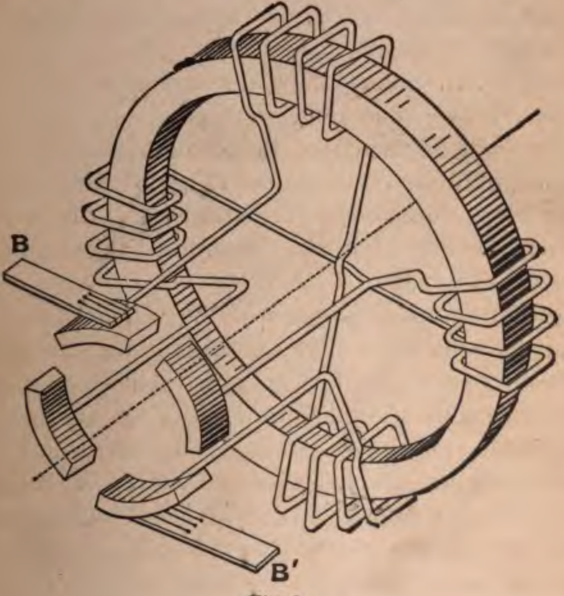

Fig. 2.

same number as the coils; and special provisions are required to prevent the spaces between segments from becoming clogged with conducting material as copper-dust, or carbonized oil, by which the insulation is reduced or suspended.

CLOSED CIRCUIT AND OPEN CIRCUIT ARMATURES.— In some armatures the coils connect with each other all around in a closed circuit, while each one connects also with a separate segment of the commutator, as shown in Fig. 1. In others they are arranged in pairs on opposite sides of the ring, each pair being connected with opposite segments of the commutator, and independent of all others, as shown in Fig. 2. The first kind are known as closed circuit armatures, as in the Gramme dynamo; the second kind as open circuit armatures, as in the Brush dynamo.

THE BRUSHES. — The brushes by which the electric current is taken up and transferred through conductors to the lamp are shown in Fig. 2, in their usual position in contact with the commutator. They are made of copper, and are of different styles, as shown in Fig. 3, which shows the under brushes as viewed from above; the style at A consisting of two layers of wires soldered together at the upper end; the one at B, of two broad strips divided as shown for a certain distance from the lower end; the one at C, of several undivided strips of different lengths, overlapping each other. Sometimes two of these styles, as A and B, or A and C, are combined in the same brush. The main object is to obtain the best contact at numerous points, and to prevent the waste of energy and irregularity caused by sparking at the points of contact. The brushes are held in suitable clamps in the position shown in Figs. 1 and 2, their free ends pointing in the direction in which the armature revolves; and a steady pressure is maintained by their elasticity.

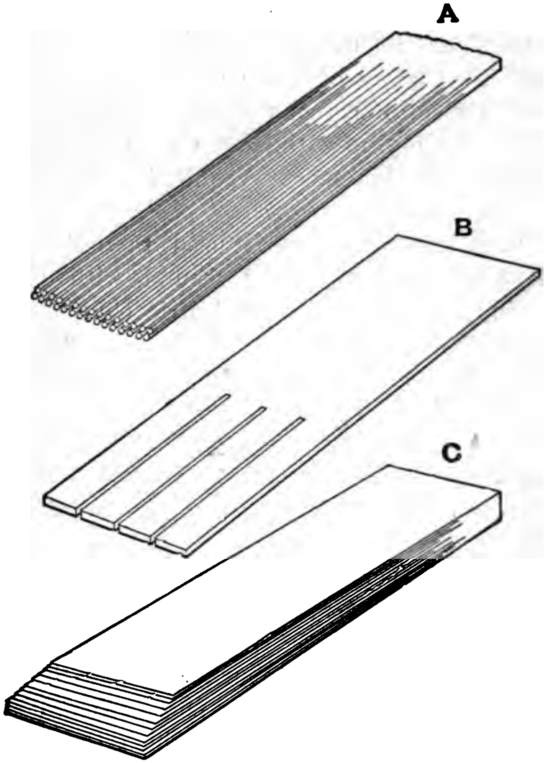

Fig. 3.

THE FIELD-MAGNETS.—In Fig. 1 we have an ideal representation of the field-magnets on each side of the armature, with their pole-pieces partly inclosing it. They may be permanent steel magnets or electro-magnets. Permanent magnets are suitable only for small hand dynamos, designed for experimental laboratory work. For this purpose the permanent magnetism is an advantage, since there can be no such increase of force as to prevent the operation of the dynamo by hand, which might be the case with electro-magnets. But the low energy of permanent magnets as compared with electro-magnets, and their liability to partial loss of magnetism with age, render them unsuitable for dynamos of the energy required for the electric light.

The term electro-magnet is used to designate any magnet having an iron core wound with insulated wire, through which wire an electric current may be transmitted: the armature itself is such a magnet. The core becomes magnetic only while the current is flowing through the wire; and its magnetism ceases with the cessation of the current, leaving only a slight trace known as residual magnetism, which in dynamos has an important function, as will be explained hereafter.

The ends of every magnet are technically termed poles, distinguished respectively as north and south by the direction in which a straight bar magnet points when freely suspended, and marked N. and S. In the dynamo, north and south poles face each other; and into the space between them, in which the armature revolves, lines of magnetic force radiate, constituting what is technically termed the magnetic field; hence the magnets are called field-magnets. They may be straight magnets, as shown in Fig. 1, a single north pole facing a single south pole; or horse-shoe magnets, two north poles alternately facing two south poles. The core should be of the best soft iron, either wrought or cast. The pole-pieces, which are considerably wider than the core, are curved on the faces, inclosing a large portion of the armature and confining all the lines of force, and are placed as close to the armature as safety of rotation will admit, so as to reduce the magnetic resistance to its minimum, as the lines of force traverse the field; the resistance of the air being immensely greater than that of the iron core of the armature.

Cast-iron is generally used for the pole-pieces, but wrought-iron is sometimes preferred; and a laminated structure, composed of numerous thin layers combined, is also recommended; the object being, as in the armature core, to give the lines of force their proper direction.

Large wire, well insulated, is as essential for the winding of the field-magnets as for that of the armature, for the reasons already given; and a greater body of wire in the central portion of the magnet than near the ends is recommended, as giving a more even current, less subject to sudden fluctuation, which, in an electric-light dynamo, is a very essential point.

THE DYNAMO'S MODE OF ACTION.—It has been shown that lines of magnetic force from the poles of the field-magnets radiate into the space between them, known as the magnetic field. The direction of these lines is from the pole technically known as the north to the one known as the south pole; and their number may be considered infinite throughout the field, though more numerous in some parts than in others. When a coil of wire is rotated in this field, temporary electric currents circulate in the wire at right angles to the magnetic lines which pass through the coil, and the electromotive force of this current varies as the number of those lines.

DIFFERENCE OF POTENTIAL.—It is absolutely necessary, in the generation of these currents, that the magnetic intensity should vary, or, as technically termed, that there should be a difference of magnetic potential at different points; and this difference is produced by the different relative positions of the armature coils, as they rotate, with reference to the lines of force. As the object of every electric generator is to create and maintain a difference of electric potential, it is evident that if the armature rotated in a uniform field with its axis parallel to the magnetic lines, so that the number intercepted by its coils was always the same, there would be no difference, either of magnetic or electric potential, and hence no current. The generation of current depends on the fact that the coils cut across those lines, continually changing position and intercepting a number varying from zero to a maximum; the position of each coil with reference to the lines being alternately reversed by the rotation of the armature, at each half-revolution, as shown by Fig. 4, producing alternate reversal of current.

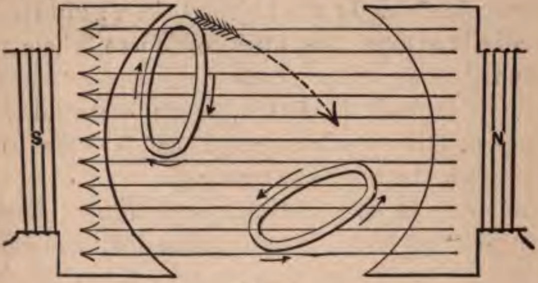

Fig. 4.

The current always flows from the point where the electric pressure is greatest to the point where it is least; that is, technically, from higher to lower potential, just as water flows from a higher to a lower level, or steam rushes through a pipe from where the pressure is greatest to where it is least.

REVERSED CURRENTS.—The direction of the current, as stated, is always at right angles to that of the magnetic lines; and when by the rotation of the armature the movement of the coils, as viewed from the pole toward which the magnetic force moves, is upward next that pole, the current circulates in the coils in the same direction as the hands of a watch move, as shown at the upper left hand corner of Fig. 4; but when the movement is downward next the pole from which it moves, the direction of the current is reversed, as shown at the lower right-hand corner; the latter direction being known as the positive sense, and the former as the negative.

It is evident, then, that at each revolution of the armature two distinct electric currents are generated in its coils, one during each half-revolution; that each coil passes through two neutral points where the currents reverse, and where it intercepts a minimum number of the magnetic lines, and also through two points where it intercepts a maximum number. The generation of current begins at the instant the first neutral point is passed, increases as the difference in the number of lines intercepted per unit of time increases, diminishes as this number decreases, and ceases at the second neutral point. Here a new current begins, which passes through the same phases of increase and decrease during the second half-revolution, and the relative position of the coil being reversed the direction of the current is reversed also.

Each of these currents is transitory, its rise, fall, and reversal occupying only an instant, and passing into the external circuit through the brushes and commutator, or collector, as an undulation; and the continuous current of the dynamo is composed of a succession of these transitory currents, and is direct, if passed through a commutator, but otherwise, alternating, as explained hereafter.

It is not essential to the generation of an electric current that the wire should be in the form of a coil; a straight wire, or one bent into any conceivable shape, and forming part of a closed circuit, if moved through a field of varying magnetic intensity by rotation, or in any other manner, will have electric currents generated in it, whether it moves from greater to less, or from less to greater intensity. Or such a wire or coil, if moved through a perfectly uniform field in such a manner as to intercept a varying number of lines of force, per unit of time, will have electric currents generated in it. It is evident, however, that a perfectly uniform field between opposite north and south poles is a practical impossibility, magnetic intensity, north or south, decreasing from one pole to the other, each kind in the inverse ratio of increase in the opposite kind. The chief advantage of the coil consists in its capability of inclosing an iron core, which by its magnetic conductivity intercepts and leads the lines of force through it, in close proximity to the inclosing wire, so as to produce the highest inductive effect.

According to a theory now somewhat obsolete, the currents are generated by the lines of force threading through the coils, the interior wire thus taking part in the generation equally with the exterior; but experiment seems to prove that this theory is fallacious, as no current is found in the interior and end wire when not continuous with the exterior; its office being apparently that of a conductor of the currents generated in the exterior wire.

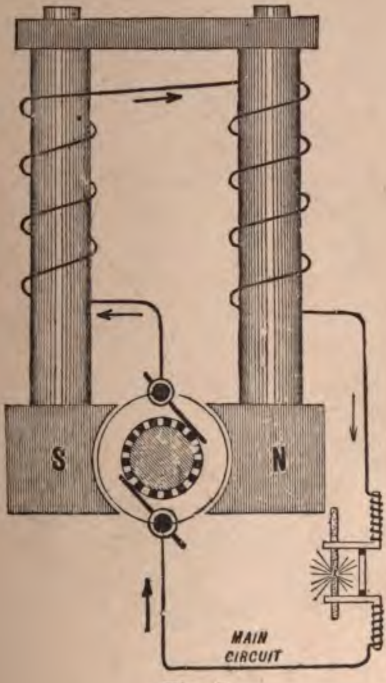

Fig. 5.

Commutation.—By reference to Fig. 5, it will be seen that the currents generated in the armature are taken up by the brushes and circulate in the direction shown by the arrows through the coils of the field-magnets and the external circuit in which the lamp is placed. If there were no commutator, the currents in this circuit would be alternately reversed, and we would have the alternating-current dynamo, which constitutes a distinct class; but it will be seen by Fig. 6 that at the instant the armature current is reversed, the position of the opposite segments of the commutator with reference to the brushes is reversed also, each segment as it moves out of contact with one brush moving into contact with the opposite brush, so that each transitory current, generated in the connected coil, passes into the external circuit in the same direction by this commutation; for, as shown in Fig. 4, the current is always in the same direction in each of the two opposite positions of the coils, hence if taken up by each brush before reversal, all the currents must

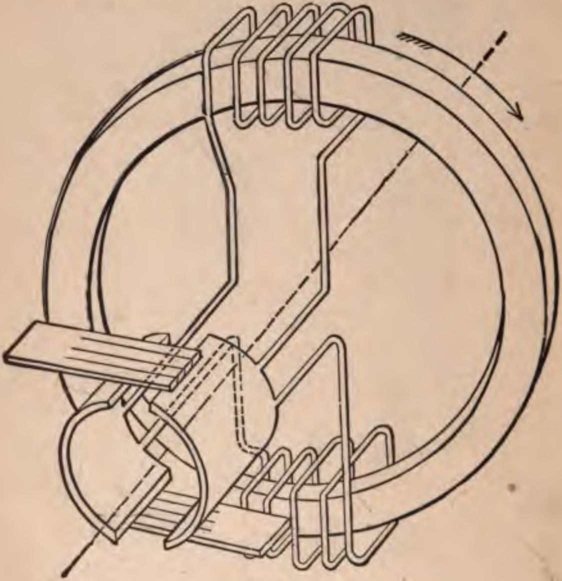

Fig. 6.

pass out of the armature at one brush and into it at the other, as shown in Fig. 5, and therefore flow in the same direction through the external circuit.

But if there were only two segments and two coils, it is evident that a break in the current would occur at each half-revolution. But with four segments and four coils at right angles to each other, as shown in Fig. 7, and the brushes so constructed as to make contact with the approaching segment before breaking contact with the receding segment so as to bridge the intervening space, the current becomes continuous, one pair of coils generating current while the other pair is passing the neutral points. But the current though continuous, would be uneven, rising and falling in waves as the coils passed *from the neutral to the* maximum points, and round

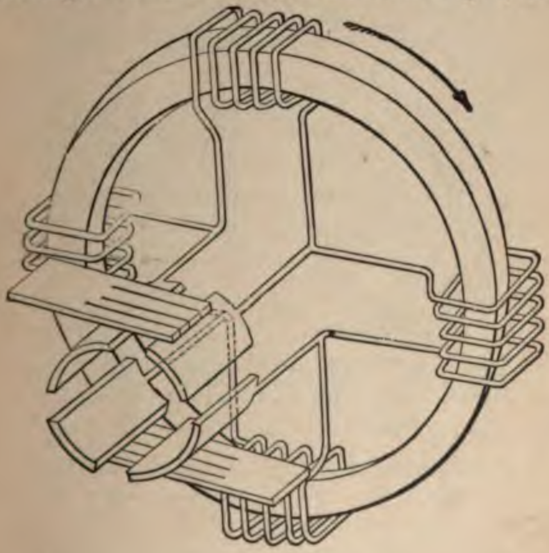

Fig. 7.

again to the neutral. This is corrected by multiplying the coils and segments, as shown in Fig. 1 (page 15), thus multiplying the number of waves and reducing their length and intensity in the same ratio.

In closed circuit armatures, as shown in Fig. 1, all the transitory currents on the same side reinforce each other, the coils being all connected together, and each connected also with a separate segment of the commutator, so that each coil has constant connection with the brushes, through the commutator, during the entire revolution of the armature. Hence if the brushes were placed at the maximum points it is evident that the opposite coils on each side would be carried past the neutral points by rotation before the connected commutator segments reached the brushes, and the generated currents be neutralized by the generation of reversed currents of equal strength, and the external current cease. But when the brushes are placed at the neutral points, all the currents generated on the left, when the rotation is in the direction of watch hands, as in Fig. 5, pass into the external circuit by the upper brush, while those generated on the right are augmented by the current flowing in from this circuit by the lower brush. Hence since no external current is obtained with the brushes at the maximum points, while a maximum current is obtained when they are at the neutral points, it is evident that, in any intermediate position, there must occur a partial neutralization by opposing currents; the neutralization decreasing and hence the electromotive force increasing as the brushes approach the neutral points, and these conditions being reversed as the brushes approach the maximum points.

By attaching the brushes to an insulating yoke by which they can be moved simultaneously to any two opposite points, the electromotive force and resulting current can thus be regulated as required, within certain limits. But such regulation tends to increase sparking at the brushes, a wasteful and injurious heating effect, difficult to suppress. Dynamos with open-circuit armatures are susceptible of similar regulation.

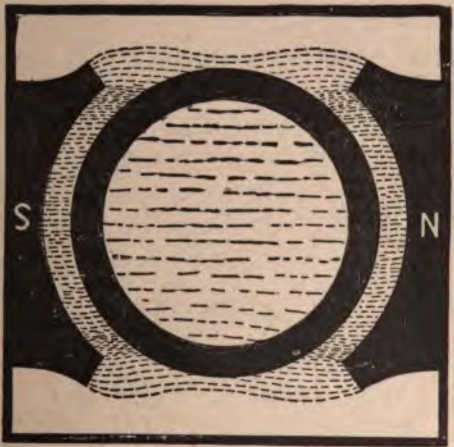

Fig. 8.

THE ARMATURE'S MODE OF ACTION.—If the armature were constructed without a core, or with one of high resistance, its energy would be comparatively low, depending solely on the electricity induced in its coils by the field-magnets. The principal advantage of the iron core consists, not only in furnishing a medium of high magnetic conductivity by which the lines of force are led into close proximity with the coils without loss, but chiefly because it makes the armature itself an electromagnet, acting reciprocally with the field-magnets to multiply the magnetic and electric effects by mutual reaction. In an armature without an iron core the lines of force would run nearly parallel from pole to pole; the concavity of the pole-pieces producing parallelism in lines which would be divergent if radiated from one plane surface to another. The same parallelism is found to exist when the magnets are separately excited, and the armature is not rotating, as shown in Fig. 8, where the lines passing into the armature in the central

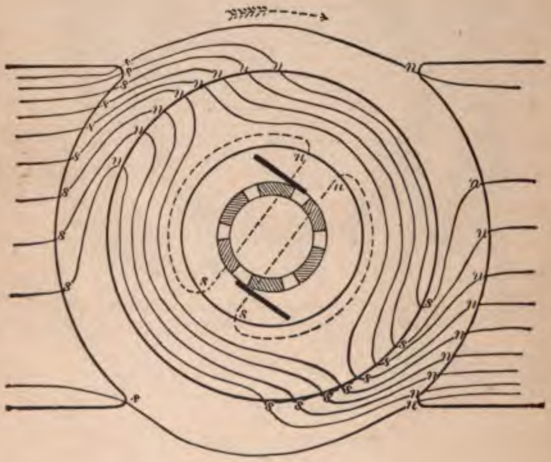
Fig. 9.

region are seen to be parallel, while those at the extremities of the pole-pieces, above and below, are slightly curved. It will be noticed that the lines are denser near the extremities of the pole-pieces than in the center, and that the relative number passing through the interior of the armature is comparatively small.

The field-magnets induce opposite polarity in those portions of the armature core adjacent to each pole, as shown in Fig. 9, while the electric currents circulating in the armature coils induce in the same parts of the core, polarity similar to that of each field-magnet pole, north polarity on the right and south polarity on the left, when the rotation is in the direction indicated by the arrow. This polarity is much stronger than that induced by the field-magnets, and on account of the mutual repulsion between these poles and the similar poles of the field-magnets they are deflected into a position nearly at right angles to that of a line joining the field-magnet poles, as shown in Fig. 9, the north pole upward to *n n*, and the south downward to *s s*, the field-magnet poles being, for the same reason, deflected into the positions indicated in each by the letters *n* and *s*. Hence the lines of force become greatly contorted, as shown.

But the armature core does not become fully magnetized at the instant induction occurs, nor fully demagnetized at the instant it ceases, an infinitesimal moment being required for magnetic saturation in the first instance and demagnetization in the second, known as *magnetic lag*, during which its poles are moved slightly forward by the rotation, increasing the contortion of the lines.

These positions of the armature's poles become comparatively stationary, varying slightly with the speed of rotation, the core rotating through them, and the magnetic strength and polarity of each portion changing with its position. Hence the neutral line, where the currents reverse, is through the armature's principal poles, *n n* and *s s*, its position being diagonal to that of a line through the centres of the pole-pieces.

When a new dynamo is completed and ready for use, it is found that the iron, during the various manipulations to which it has been subjected, has become slightly magnetic; and this residual magnetism, as it is termed, is the germ of magnetic and electric energy from which the full power of the machine is derived.

When the armature begins to revolve, and its coils intercept the lines of force from this residual magnetism, found in the field, incipient electric currents are generated in them, which, having been commuted into a single direct current and taken up by the brushes, circulate through the coils of the field-magnets. These incipient currents induce magnetism in the cores, and thus increase the magnetic intensity of the field, so that the armature coils intercept an increased number of lines of force. This increases the magnetism of the armature core, inducing greater energy in the electric currents generated; and these currents, passing into the field-magnet coils as before, continue to increase the magnetic intensity of the field. Thus, magnetism augments electricity, and electricity reacts to augment magnetism; and this series of reciprocal reactions between the armature and the field-magnets, and between the magnetism induced in the cores of each and the electricity induced in their coils, increases the magnetic and electric intensity of each in geometrical ratio, so that in a few moments the incipient current, induced by the feeble germ of residual magnetism, has become the powerful current which produces from a series of arc lamps a light of 100,000 candle-power.

When a dynamo stops running, its electric and magnetic energy cease, but it still retains the residual; so that, when put in operation again, its energy is rapidly developed, and the electric current generated as in the first instance.

It is evident from the manner of electric development as described above, that the electric energy generated must vary as the speed of rotation of the armature, so that the more rapid the rotation, the greater the energy developed. But there are certain limits which cannot be exceeded, dependent chiefly on the strength of material and the incidental development of heat. If the limit of strength is exceeded, the armature is liable to fly in pieces; and if too much heat is developed, the insulating material may be charred and permanently injured, or the electric and magnetic properties of the metals be temporarily reduced. The development of a certain amount of heat is inevitable, and it varies in different dynamos according to the method of construction. Hence the adjustment of speed in each case becomes an important item. Taking the number of feet in the circumference as a basis, the rate of speed in most dynamos varies from two to three thousand feet per minute, while in some it equals five thousand; that is, that number of feet of circumference passes a given point in a minute; and the number of revolutions per minute, in any case, can be ascertained by dividing by the number of feet in the given circumference.

To the ordinary observer, not versed in electric science, and especially to the mechanic, accustomed to visible, tangible resistance requiring power to overcome it, the resistance of the dynamo is a profound mystery. Here is an armature capable of being put in rotation by a few pounds pressure applied with the hand, and rotating apparently in empty space; but through some invisible agency the resistance increases with the speed, till, in a few moments, an engine of a hundred horse-power is required to sustain the rotation. But this apparently empty space is the magnetic field through which radiate an infinite number of lines of force, cut by the armature coils, and generating the electric current in the manner described; so that the resistance, though invisible, is as real as that of the machinery of a factory. It is, in this respect, a resistance similar to that of gravity, unseen, intangible, yet real.

SERIES SHUNT AND COMPOUND WINDING.—Dynamos are divided into three classes, according to the method in which the field-magnets are wound and the relations of this winding to the external circuit, known respectively as *series*, *shunt*, and *compound* wound. In the series wound dynamo, illustrated by Fig. 5, the entire current traverses a single route of low resistance, passing in series through the armature coils, field-magnet coils, and external circuit, back to the armature; so that any variation of resistance, at any point, as by the introduction of a lamp or otherwise, affects the whole series equally; the current strength varying inversely as the resistance.

In the shunt winding, illustrated by Fig. 10, two distinct circuits are provided, an external circuit of coarse wire, and hence of low resistance, and a shunt circuit of fine wire and high resistance, wound on the field-magnets. The current divides at the upper brush in the inverse ratio of the resistance of each circuit, 1½% to 20% traversing the shunt and employed exclusively to excite *the field-magnets*, while the main current flows through the external circuit and is employed for useful work, as the production of light.

If the resistance of the external circuit is increased, as by the introduction of a lamp, the strength of its current is proportionately diminished; but the potential difference, or electromotive force, between the brushes, representing the electric pressure, is increased by the diminished flow of current in the ratio this increased resistance bears to itself plus the armature's resistance: and as the resistance of the shunt remains constant, the strength of its current is proportionally increased by this increase of electromotive force; and the magnetism of the core

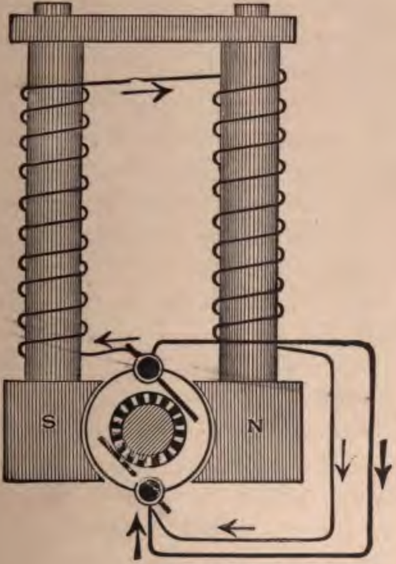

Fig. 10.

being increased in the inverse ratio of its magnetic saturation by this increase of current strength in the shunt, its reaction increases the current strength in both circuits, thus supplying electric energy to overcome the increased resistance. By this series of adjustments an equilibrium between these various factors is established, the total electric energy developed varying as the mechanical energy expended. Decrease of external resistance reverses these results.

This increase of current strength in the shunt is relatively small as compared with decrease of that in the external circuit. Current is not diverted from one branch to the other, which would imply that the strength of the shunt current is increased to the same amount as that of the external circuit is diminished, but varies as the relative conditions of resistance and electromotive force vary with respect to the relative capacity of each branch of the circuit. The resistance of the shunt may be varied as required by resistance coils.

The compound winding, illustrated by Fig. 11, is a combination of the series and shunt methods; a shunt circuit of fine wire and high resistance being employed exclusively to excite the field-magnets, while a coarse wire circuit, of low resistance, is also employed for the same purpose, and connected with the external circuit, as in the series method. The automatic regulation is similar to that of the exclusive shunt method, except that the entire current flows through the field-magnet coils. This method is susceptible of very delicate adjustment and regulation by adjusting the relative resistances of the two circuits.

Each of these three methods of winding has its special adaptation to the requirements of a certain kind of work.

In electric lighting it is found that the series wound dynamo is usually the most suitable for arc lighting, and the shunt and compound wound for incandescent lighting; arc lighting requiring high electromotive force and comparatively small current, while the requirements for incandescent lighting are the reverse: which leads to the classification given below.

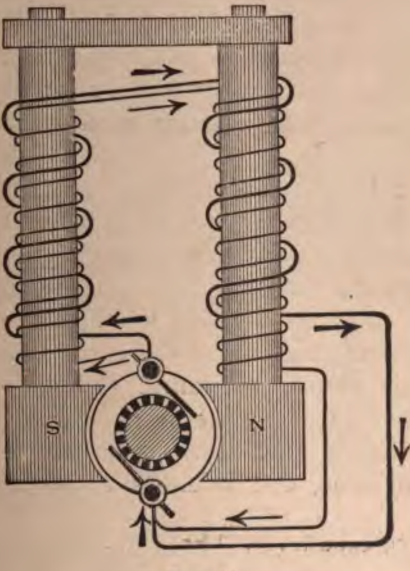

Fig. 11.

Constant Current Dynamo.—To maintain a number of arc lamps, connected in series, at a given illumination, a constant current flowing from lamp to lamp is required for each. If but one lamp were lighted the required electromotive force, or potential, would be comparatively small; but if two were lighted, the resistance being doubled, the electromotive force must be doubled to maintain the same current strength; and the same ratio of electromotive force to resistance must be maintained for any number lighted or extinguished.

Hence the construction and regulation of a dynamo for such work must be such as to furnish electromotive force capable of variation within the required range; and a machine so constructed is known as a *constant current* dynamo, and is usually series wound, as stated above.

CONSTANT POTENTIAL DYNAMO.—But if the required work were the maintenance of a number of incandescent lamps connected in parallel, the lamps being on branches derived from the main circuit, the variation of resistance is confined to these branches, in which it becomes adjusted to the requirements of the current, the resistance of the main circuit remaining constant; hence the electromotive force remains nearly constant, and a machine adapted to such work is known as a *constant potential* dynamo, and is either shunt or compound wound.

DIRECT CURRENT AND ALTERNATING CURRENT DYNAMOS.—Dynamos are divided, according to the nature of the current generated, into two classes, the direct current and alternating current, according as the current flows continuously in one direction, or alternately in opposite directions. For some purposes, especially that of electroplating, a continuous current in one direction is an absolute necessity, as a reversed current would, in this case, remove the metal deposited by the direct current; but in electric lighting, it is a matter of less consequence, continuity and steadiness being of more importance than direction of current.

It has already been shown that the continuous current is made up of a succession of transient, momentary currents collected into one; and that, by means of the commutator, these are all made to flow in the same direction. But for the purpose of continuity, it is immaterial whether these momentary currents are in the same direction or in opposite directions, provided there is no perceptible break between them. The case is analogous to that of a circular movement as compared with an oscillating movement in mechanics: the rapidity of movement in each case may be such that the eye can not distinguish between the separate impulses, so that the oscillating may appear as continuous as the circular.

CHAPTER III.

DIRECT CURRENT DYNAMOS.

DIRECT current dynamos are divided according to the number of poles in the field-magnet into two classes, known respectively as *bipolar* and *multipolar;* the bipolar having only two field-poles, and the multipolar any number more than two. A few leading dynamos of each class will illustrate the different methods of construction; and the bipolar being the simplest, and the type employed in illustration of the principles of the dynamo, in the previous chapter, may appropriately be described first.

THE EXCELSIOR DYNAMO. — This dynamo, as recently improved by its original inventor, William Hochhausen, is shown in Figs. 12 and 13, which represent the largest size made, capable of lighting 100 arc lamps, of 2000 candle-power each.

Its armature core is constructed of iron wire, wound on a cast-iron frame having a T section which divides it into two equal parts, as viewed edgewise. This core is mounted on a spider attached to the shaft, the arms of which are insulated from the core. The armature is of the Gramme, or ring, type, and, in machines of the size here shown, is 30 inches in diameter and 8 inches thick, and has 160 pounds of No. 16 insulated copper wire wound on its core, in 36 coils as shown. These coils are rectangular, each being 8 inches square, and are separated from each other by wooden wedges attached to the cast-iron frame, to the outer ends of which are screwed blocks of insulating fibre which hold the coils in position.

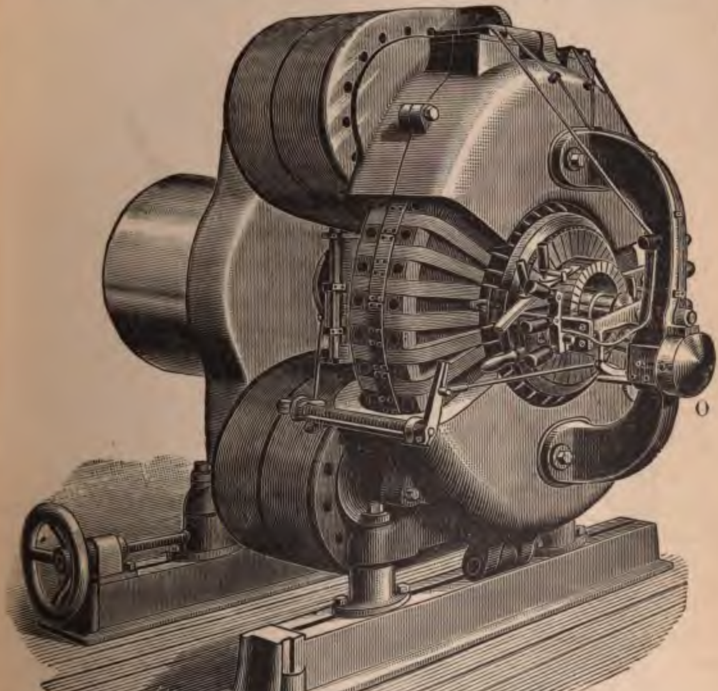

Fig. 12.

The field-magnet consists of a vertical cast-iron yoke, connecting two horizontal cast-iron cores, on which are wound 1300 pounds of No. 8 insulated copper wire, in two coils, connected in series with the armature and external circuit. Each of these coils is divided into two

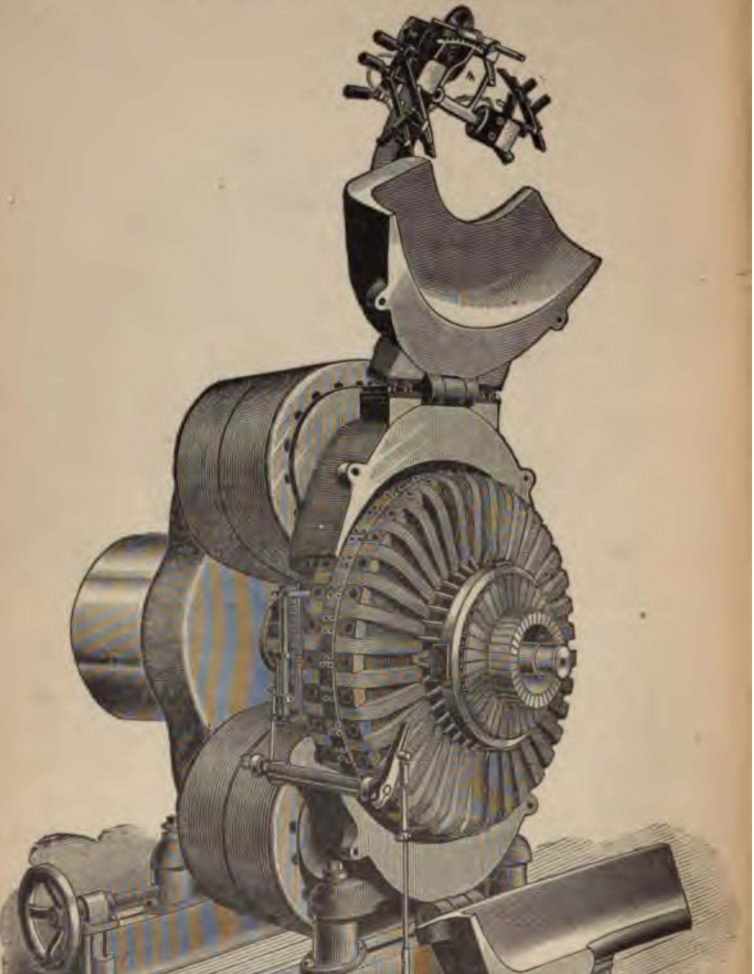

Fig. 13.

sections as shown; and each front section is tapped at equal intervals by 10 wires, making 20 subsections in the two, which are connected by these wires with a field-switch which forms part of the system of automatic regulation described hereafter.

The armature is supported on interior bearings, not shown in the cuts, and is partly inclosed by the cast-iron pole-pieces attached to the magnet cores. Each of these pole-pieces is made in two sections, hinged together so that they can be opened, as shown in Fig. 13, to allow the armature to be drawn out for repairs, without removing the shaft from its bearings. To the outer section of each pole-piece is bolted a curved arm; the upper arm supporting the brushes and part of the regulating apparatus, as shown in Fig. 13; these arms being bolted together when closed, as in Fig. 12.

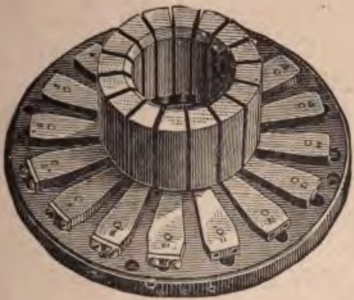

Fig. 14.

The commutator consists of the usual copper segments, to each of which is attached an arm, at right angles, as shown in Fig. 14; and these arms are bolted to a marble disk inclosed by a copper band; so that the *segments are insulated* from each other by air spaces instead of the usual solid insulating material, and the supporting arms by the marble. This construction gives the commutator the best possible interior ventilation; the segments projecting into the air, without interior support, so that it is impossible for it to be injured by heating; and also allows any segment to be removed for repairs without disturbing the others.

The automatic regulation of this dynamo is one of its most notable features. It is controlled by a small motor, inclosed in the circular box shown at O in Fig. 12, which is attached to the upper curved arm. These arms are insulated from the pole-pieces by hard-rubber, so that only a small number of the magnetic lines of force traverse them; barely enough to create a magnetic field of sufficient strength for the operation of this little motor, without serious reduction of the strength of the main field in which the armature of the dynamo revolves. This motor is constructed with a little armature, shown in Fig. 15, which rotates in this field, and is connected with the electric circuit of the dynamo by two little brushes, from which conducting wires extend to a controlling electromagnet M M, and resistance coils of German silver wire R^1 R^2 R^3, contained in a case attached to the wall; this part of the apparatus being known as the *wall controller*.

This apparatus regulates the electric current not only by moving the main brushes on the commutator to or from the neutral line, but also by increasing or decreasing the number of sections of the field coils through which this current is flowing; cutting out sections as the brushes are moved from the neutral line, and thus reducing the electromagnetic energy of both the field and the armature, and reversing this operation as the brushes are

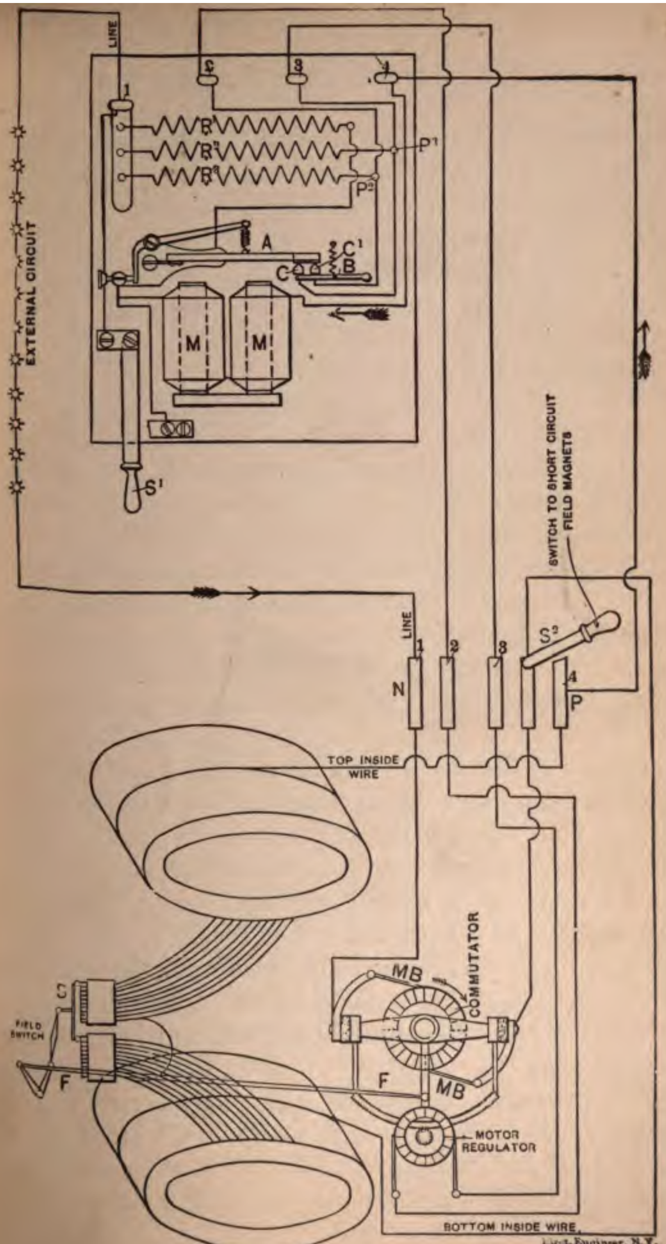

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Fig. 15.

moved toward the neutral line, and thus increasing this energy.

The manner in which this is accomplished will be understood by an examination of the diagram shown in Fig. 15, in which an outline of the field-magnets with the 20 wires connecting the coil sections with a sliding field switch is shown on the left below, and the commutator and motor regulator on the right; all connected with the wall controller above, and with the external circuit.

It will be noticed that the little motor is geared by a curved rack to a yoke or rocker to which are attached the main brushes M B M B, and that the rod F F, which operates the field switch S, is connected with this rocker by a vertical arm; therefore as the main brushes are moved *from* the neutral line, the upper to the left and the lower to the right, the field switch S is pulled down, cutting out sections of the field coils; but when the movement of the brushes is in the opposite direction this action is reversed.

Following the course of the current as indicated by the arrows, we find that it passes from the upper field-magnet coils through the top inside wire, positive terminal P 4, binding-post 4 in wall controller, coils of electromagnet M M, hinged lever armature A, resistance coil R^1, binding-post 1, line and external circuit, to negative terminal N 1, upper main brush M B, through the armature coils to lower main brush M B, and thence by terminal at S^2 to bottom inside wire and lower field-magnet coils.

The lever armature A, when perfectly horizontal, as shown, rests on two contact points C and C^1, attached to the lever B, and remains in this position so long as the current which traverses the magnet M M remains at its normal strength; but when the strength of this current rises above the normal, the magnetism being increased, the armature is attracted downward in opposition to the force of the spiral springs shown, and the contact at C opened while that at C^1 remains closed. But if the current strength falls below the normal, the magnetic attraction being weakened, the armature and lever B are pulled upward by the springs, above the horizontal position, and the contact at C^1 is opened while that at C remains closed.

These two contact points are connected with the brushes of the little motor below by two wires which pass upward through the posts 2 and 3, and thence downward to the motor brushes through terminals 2 and 3. These wires are tapped at P^2 and P^3 by the resistance coils R^2 and R^3, which connect them with the line and external circuit. Part of the main current can flow through the contact points C or C^1 to the motor, when one contact is open and the other closed; but when both are closed, the E. M. F., or electric pressure, being equal in both wires, and opposite in direction, there can be no current, since there is no difference of potential.

When therefore the main current rises above its normal strength, the armature A being attracted and the contact at C opened, part of the current is shunted through C^1 to the motor by post 2 and terminal 2, and entering by the left hand brush traverses the motor's armature and returns from the right hand brush through 3, 3, P^3, and resistance coil R^2, to the line. This causes the armature of the motor to rotate in such direction as to move the main brushes M B M B from the neutral line by means of the rocker, and also cut out sections of the field coils by means of the field switch S, moved by the rod F F, thereby reducing the current to its normal strength. But when the main current falls below its normal strength, the contact C^1 being opened, the shunt current passes from C, through 3, 3, to the right hand brush of the motor, and traversing the motor's armature in the opposite direction, reverses its rotation, thereby moving the main brushes toward the neutral line, and reversing the movement of the field switch, so as to increase the magnetic energy; and thus restores the current to its normal strength.

The relative quantities of current which traverse the shunt and the main circuit are regulated by a proper adjustment of the relative resistances of the coils R^1, R^2, and R^3. And the movements of the armature A are regulated by a proper adjustment of the relative strength of the magnetic attraction of the magnet M M and of the spiral springs which oppose it.

By means of the switch S^1, the motor may be cut out of the circuit while adjusting the magnet M M. And the switch S^2 is employed to produce a short circuit between the lower and upper halves of the field magnet when stopping the dynamo.

THE BRUSH DYNAMO.—The distinctive features of the Brush dynamo relate chiefly to the construction of the armature and commutator. The armature core, shown at *X*, Fig. 16, has a central ring, *B*, *B*, *B*, composed of layers of thin sheet iron ribbon, insulated by vulcanized fiber. These are separated from each other by short iron pieces, one of which is shown at *Y;* the central part of each having the same width as the ring, while at each end are projections on opposite sides, forming, when placed in the core, the V-shaped figures shown at *X;* the arrangement, when the core is bolted together, being shown in cross-section at Z. The ends of these pieces are separated slightly in the interior, and more widely at intervals in the exterior, as shown in Fig. 17. The core is bolted to an interior rim, shown in Fig. 17, which is attached at four opposite points to a spider mounted on the shaft.

This open, laminated structure affords ventilation, eliminates the Foucault currents, and gives, in the central portion, between the projections, a solid support for the coils. The old-style core, which resembles this, was of cast-iron, deeply channelled for ventilation, in the center and in each projection, but was abandoned on account of the Foucault currents and consequent heating, notwithstanding the excellent ventilation. The new core gives the dynamo an increase of more than forty per cent in efficiency.

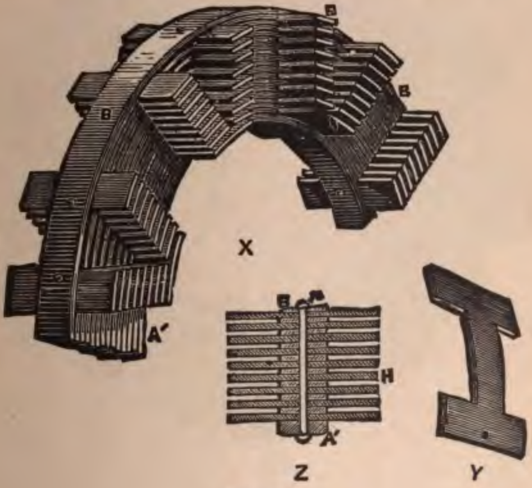


Fig .16.

The coils are wound with insulated copper wire between the projections, as shown in Fig. 17, and supported on the exterior and interior portions of the core by projecting flanges. The winding is of the open circuit type described on page 18, the coils being arranged in pairs on opposite sides of the armature, each pair forming a complete, independent circuit, the two ends of the wire being attached to opposite segments of the commutator; an eight-coil armature having four circuits and eight commutator segments, as shown in Fig. 18, in which the connections with the commutator are represented, that part of the wire connecting each pair of coils being omitted.

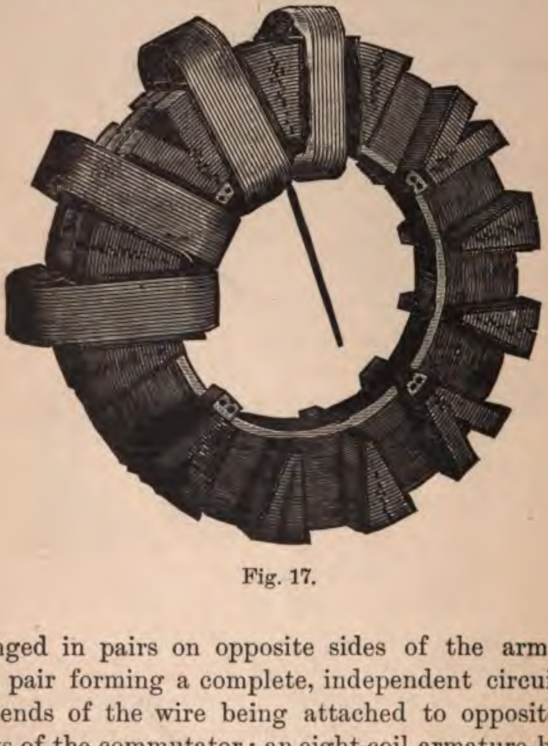


Fig. 17.

The construction of the commutator and its connection with the coils will be understood by comparing Fig. 18, showing the connection, with Fig. 19, in which it is shown in perspective. It consists of two cylinders, as shown, each having an equal number of segments; an eight-part commutator, being composed of two four-part cylinders mounted on the same shaft, in such a position that the segments on one cylinder are about one-eighth of a circumference in advance of those on the other; the narrow end of each T-shaped segment of one cylinder being placed opposite the broad end of each similar segment of the other. In the latest style the narrow part of the segment is cut off and replaced by a block of lignum vitæ, which has a copper strip on one edge to prevent wear from the brush contacts; so that each four-part cylinder has, at each end, two segments placed as shown, with narrow blocks between. The segments are of copper, separated by air spaces, and screwed to segments of brass mounted on two concentric interior cylinders, one of vulcanized fiber, immediately under the brass segments, and the other, which is attached to the shaft, of lignum vitæ.

It will be seen from Fig. 19, that while the brushes *A*, *A′*, are each in contact with a single commutator segment, the brushes *B*, *B′*, are each in contact with two segments; and by comparing this with Fig. 18, it is seen that *A*, *A′*, are thus connected with coils 3, 3, while *B*, *B′*, are connected with coils 2, 2, and 4, 4; coils 1, 1, being disconnected. *B*, *B′*, are therefore connected in parallel with two pairs of coils, but not with two adjacent pairs, coils 3, 3, lying between them. Six of the eight coils are thus brought into action at once, and this represents the relative positions of the various parts constantly

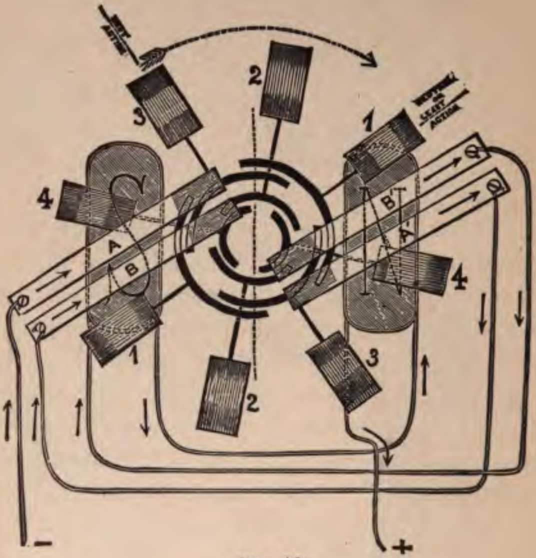


Fig. 18.

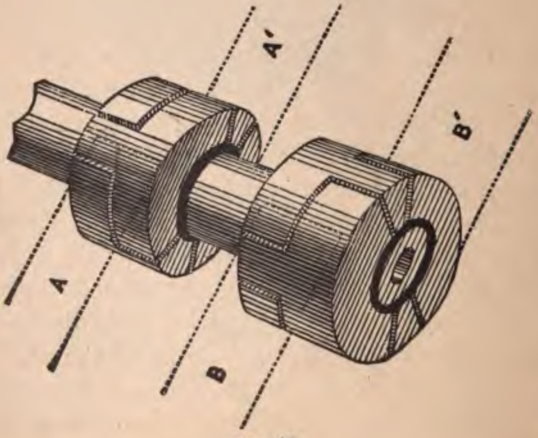


Fig. 19.

during rotation. Coils 3, 3, are in the line of greatest variation of magnetic intensity and consequently of best action, and are joined through the external circuit by the brushes *A*, *A′*; coils 4, 4, approaching this position, and coils 2, 2, leaving it are joined in parallel by the brushes *B*, *B′*; while coils 1, 1, being in the line of least variation of magnetic intensity, and consequently of least action, are disconnected. The current from the external circuit entering at *A* and traversing coils 3, 3, leaves at *A′*, thence returns through the external circuit to *B*, and traverses coils 2, 2, and 4, 4, leaving by the external circuit at *B′*, and thence returns again to *A*, completing the circuit. It is thus seen that the positive current is from coils 3, 3, where the electric potential is highest, to coils 2, 2, and 4, 4, of lower potential, from their position, and of less resistance from being joined in parallel, and thence negatively back to 3, 3.

It is evident that such an armature may be composed of any even number of coils, arranged as described. The armature of the largest Brush dynamo has sixteen coils. The copper segments of the commutator are attached with screws, and easily removed for repairs or renewal.

Two styles of the Brush dynamo are now made, one for arc lighting, series wound as formerly, and the other compound wound for incandescent lighting. The automatic, rotary movement of the brushes on the commutator, already referred to, has been recently adopted, and is used in both machines. The arc-light machine is shown in Fig. 20. The field-magnets, which are of the horseshoe type, are placed on opposite sides of the armature as shown. Those of the arc-light dynamo are wound with

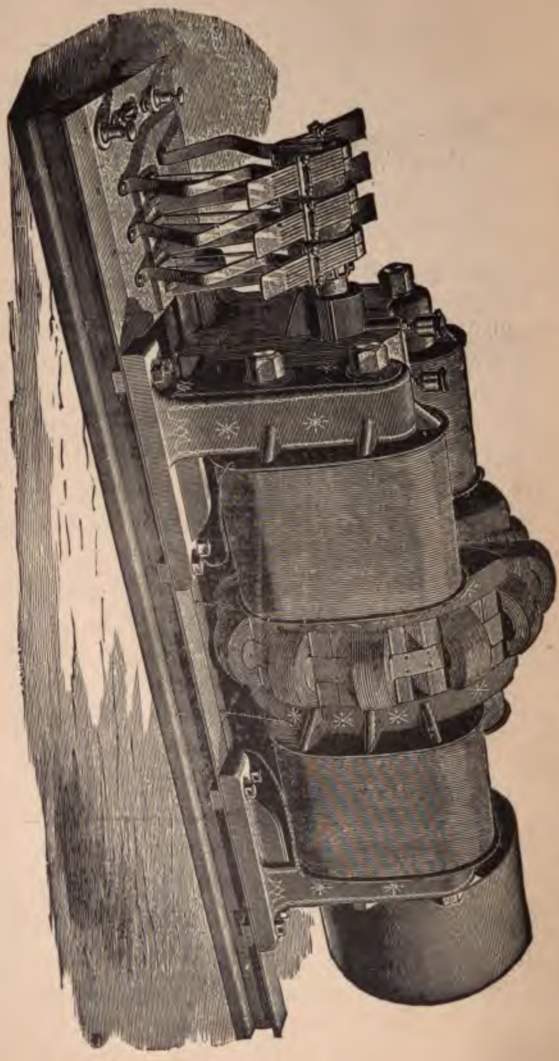


Fig. 20.

large wire, and have also an interior fine wire used as a shunt in regulating the lamps. The magnets of the compound wound dynamo have large wire next the pole-pieces, and fine wire next the magnet yokes. It will be noticed that the planes of the armature coils are at right angles to the plane of rotation, and cut the lines of force in a different manner from any of the dynamos thus far described; and that the core projections, coming close to the pole-pieces, lead the magnetism through the coils.

The E. M. F. is regulated by a device consisting of clutches, gearing, and pulleys, operated by an electro-magnetic wall controller, through which a small fraction of the current is shunted. The position of the brushes on the commutator is shifted automatically by this device, as the number of arc lamps supplied simultaneously with current varies; and thus constancy of current is maintained through each lamp, by varying the E. M. F. in the same proportion as the electric resistance of the lamp circuit varies.

THE THOMSON-HOUSTON DYNAMO.—This dynamo has a very peculiar construction. Its armature, shown in Fig. 21, is nearly spherical. The armature core, shown in Fig. 22, consists of two cast-iron flanges, G, G, the one on the left shown in elevation, and the one on the right in section. These are attached to the shaft, and connected by twelve cast-iron ribs, D, D, as shown, supported by the flanges, but insulated from them. These ribs are over-wound with several layers of annealed iron wire, coated with shellac, filling the exterior space between the flanges, as shown at I. At the ends and center of each rib are inserted projecting wooden plugs, shown at P, P, P', thirty-six in all, designed to sustain the coils in position. The core thus constructed is covered with several thicknesses of paper for insulation. The three coils, composed of insulated copper wire, form an open circuit and are connected with a copper ring at *a*, Fig. 21; and each of them, starting from this ring at distances apart of one hundred and twenty degrees, are wound between the wooden plugs over the core in the direction of its axis, as shown, in the following order: 1. First half of first coil. 2. First half of second coil. 3. Whole of third coil. 4. Second half of second coil. 5. Second half of first coil. In this way each coil is placed at the same average distance from the core. When the winding is completed, the free ends of the three coils, shown at *f*, are led through an opening in the shaft, and attached to the three segments of the commutator, and the armature is bound

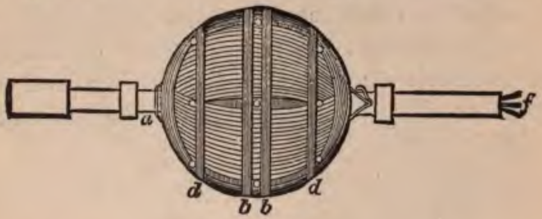


Fig. 21.

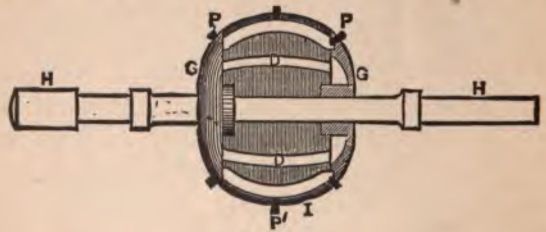


Fig. 22.

together in the usual manner by bands of brass wire shown at *b b*, *d d*.

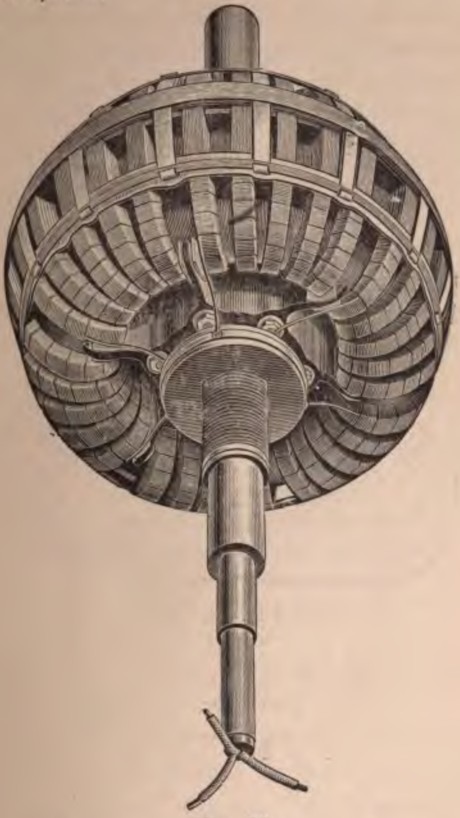


Fig. 23.

The ring armature, shown in Fig. 23, is now used on machines of the larger size. It is constructed with a laminated core mounted on two gun-metal spiders, bolted together and supported on opposite ends of the shaft, and removable for repairs of the coils.

There are thirty coils, arranged in six sets of five coils each, as shown; each coil being shaped as shown in Fig. 24, constructed of insulated copper wire, wound separately on a form before being placed on the core, and covered with insulating tape on the lower parts and ends. They are separated from each other on the inner part of the ring by strips of wood, and on the outer part by wooden blocks placed under the central wire band, and the five coils of each set are connected together by their terminals in grooves in these blocks.

The sets on opposite sides of the ring are cross-connected at the pulley end by their terminals, in three pairs, as shown at B in Fig. 25; set 1 being thus connected to set 1′, set 2 to set 2′, and set 3 to set 3′; these connections being made on a wooden disk. Three of the six remaining terminals are connected at the commutator end, to a copper ring, as shown at A, and the other three, alternating with them, are brought out through a tube, as shown in Fig. 23, and connected with the three commutator segments; the terminals of sets 1, 2, and 3 being connected with the commutator segments, and those of 1′, 2′, and 3′ with the ring.

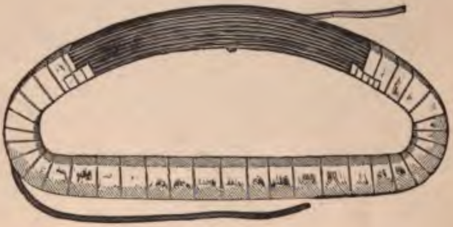


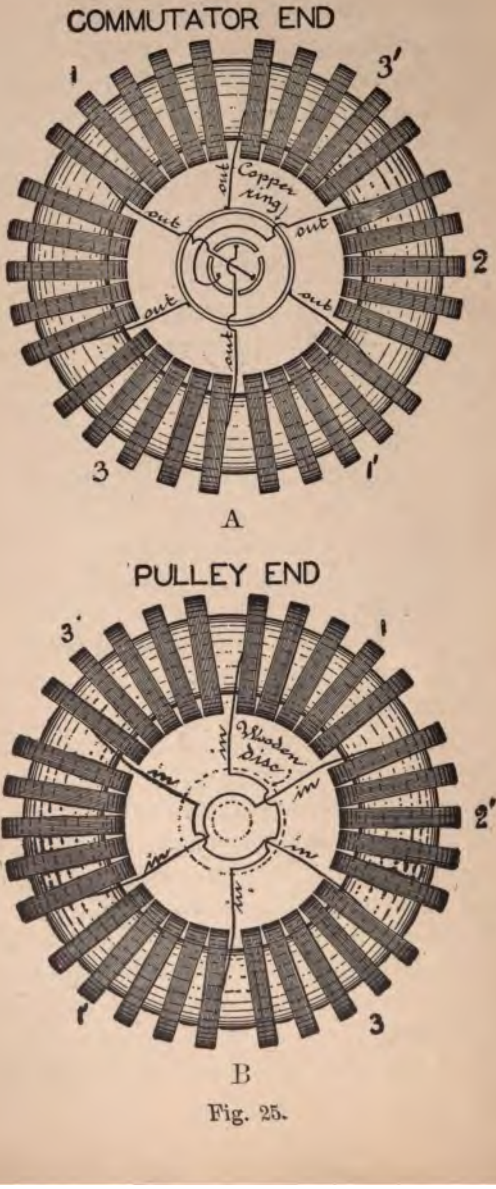
Fig. 24.

Hence the current entering the armature from the lamp circuit by the lower pair of brushes and commutator segment, traverses the coils connected with that segment, and returns by the cross-connection and opposite set to the ring, where it divides, the two halves going to the other two sets of coils connected with the ring, and returning through the cross-connections and opposite sets to the other two segments of the commutator, and thence through the upper pair of brushes to the lamp circuit.

At the next half revolution of the armature this order is reversed, the current, entering as before by the lower pair of brushes, is divided between two commutator segments, as shown in Fig. 25, at A and B, instead of being united on one, traverses the two sets of coils connected with them, and returns to the ring by the cross-connections and two opposite sets, where the two currents unite and return from the ring by the other set of coils and cross-connection to the remaining commutator segment, as shown at A, and thence through the upper pair of brushes to the lamp circuit, as before.

The ring armature can be substituted for the old style armature in machines of the same size, but many still prefer the old style.

The field-magnets, shown in Fig. 26, are constructed with two tubular cast-iron cores, open at the outer extremities, and terminating in broad flanges; while the inner extremities terminate in spherically concave pole-pieces, which nearly inclose the armature, and are furnished with brass flanges, between which and the outer flanges the magnet coils are wound, as shown at C and C'. These two cores are bolted together by bars of soft wrought-iron, b, b, connecting the outer flanges, forming virtually, when wound, one magnet, its poles facing each other in the center where the


COMMUTATOR END
1
3′
2′
2
3
1′
out
out
out
out
out
out
Copper ring
PULLEY END
3′
1
2
2′
1′
3
in
in
in
in
in
in
Wooden disc

A

B

Fig. 25.

armature revolves. The pole-pieces being inclosed within the magnet coils, and the armature brought into immediate contiguity with them, there is an increase of magnetic intensity upon the armature, which is inversely proportional to this reduction of distance, and consequently much greater than if the pole-pieces projected in the usual manner. The pole-pieces, being spherically concave, concentrate the magnetism of the field upon the spherical armature by radiation towards its center. The magnets of the arc-light machines are series wound with No. 12 insulated copper wire; those of the incandescent-light machines are compound wound, the fine wire of the shunt covering the tubular part of each core, while the coarse wire is wound in a peculiar manner close to the pole-pieces, and separated from the fine wire by the projecting flanges: hence both circuits excite the field-magnets, and, being joined at the brushes, their currents traverse the armature coils.

There are two pairs of brushes which bear on the commutator in the manner shown in Fig. 27; these, as shown in the perspective view of the dynamo, Fig. 26, are attached to a yoke, and controlled by a magneto-electric regulator placed in the circuit, and mounted on the supporting frame of the dynamo, as shown at the left. By the operation of this regulator the brushes of each pair are drawn together or separated, as shown in Fig. 27, and the current increased or diminished as required, by increase or decrease of the electromotive force produced in this manner. The rotation being in the direction of the external arrows, $m\ m'$ represents the neutral line, and the internal arrows represent the direction of the current; *consequently* when the brushes occupy

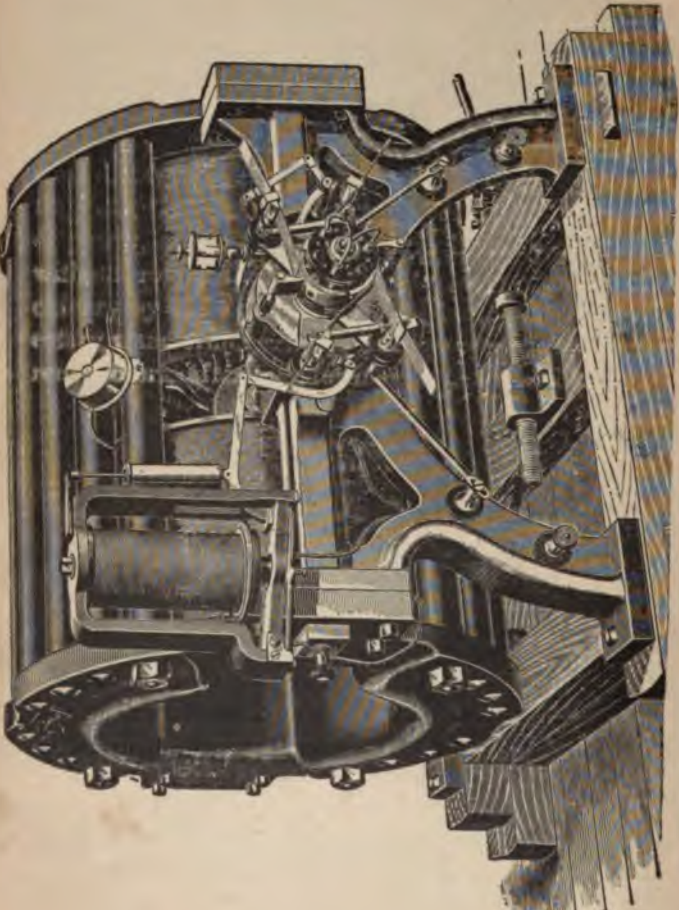


Fig. 26.

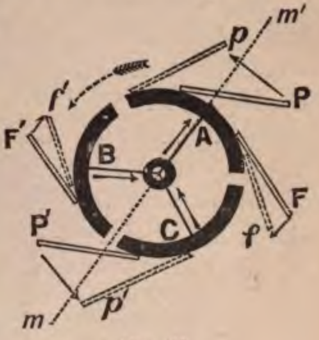


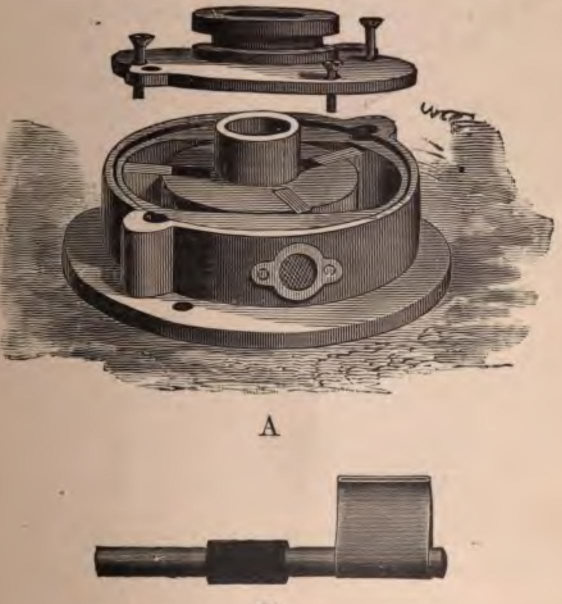
Fig. 27.

positions near this line, as at *P F*, and *P′ F′*, the electromotive force is greater than when they recede from it to the positions *p*, *f*, and *p′*, *f′*. In the first position the brushes of each pair being 60 degrees apart, and the length of each commutator segment being a little less than 120 degrees, the two brushes of one pair always bear on one segment, while each brush of the opposite pair bears on a separate segment; so that two coils are always in parallel, and are in series with the third coil, as shown. The electromotive force, under these conditions, must always be greater than when the brushes occupy the second position, the brushes being nearer the neutral line, and the time of contact with each segment in this best position being thus prolonged. But when they recede to the second position, they are farther removed from the neutral line, the time of best action is reduced, and, six times in each rotation, two opposite brushes momentarily touch the same segment, and are thus short-circuited. Hence, under these conditions, the electromotive force is reduced in proportion to the distance apart to which each pair of brushes is separated. When from a reduction of resistance in the lamp circuit by the extinguishing of a lamp, or otherwise, the current feeding the remaining lamps becomes liable to an abnormal increase, this increase is shunted through a very sensitive electromagnet, termed the controller magnet, connected with the regulator magnet of the dynamo, already referred to: the armature of the regulator is attracted, the lever connecting with the brushes is raised, the brushes separated, and the current reduced. When, from an increase of resistance in the lamp circuit, the current is diminished, this operation is reversed; the brushes drawn closer together, and the current increased; the brushes being so adjusted that one commutator segment is out of connection during each revolution. By this method constancy of current under varying resistance is maintained, the electromotive force being made to vary as the resistance. This system of automatic regulation, variously modified, is practically the same as that in use in other dynamos already described.

One striking peculiarity of this dynamo is the air-blast spark-controller, — a mechanical contrivance by which air is blown against the brushes at their points of contact with the commutator, by which means sparking at these points is suppressed.

It is shown in position in Fig. 26, just back of the commutator, and in detail in Fig. 28, and is constructed with a circular iron box, shown at A, which incloses a hard-rubber box, having an elliptic shaped interior in which a three winged blower rotates. The wings fit loosely in slots, and are driven out against the inclosing rim by centrifugal force, at the wide parts of the ellipse, and pushed in by contact with this rim, at the narrow parts; so that they are constantly in contact with the rim. The air is drawn in through two grated openings, on opposite sides at the narrow parts, accumulates in the wide parts, and is expelled against the brush contacts through two air jets which fit the circular holes shown at opposite sides; one of these jets being shown separately at B.

The three wings operate together, both as air expellers and as valves, each wing closing connection with the opening which it has passed, while the preceding wing opens connection with the one which the former wing is approaching, as shown; a partial vacuum being created by the expulsion of the air through the jets, into which air rushes through the grated openings.



A

B

Fig. 28.

Sparking at the brushes, due to self-induction in the coils of the machine, is the result directly of the passage of electricity through the air, as the brushes change from segment to segment of the commutator during its rotation, and some part of a brush is for an instant out of electric connection, all dynamos being more or less subject to it. The heat developed at the commutator by friction and electric action rarefies the air, and hence reduces its resistance, and increases the liability to sparking. Hence, a constant, strong current of cool air, such as is supplied by this air blast, increases the resistance, and, as the result shows, renders it too great for the passage of the spark. The current theory that the spark may be "blown out," in the same sense as a light is extinguished in ordinary combustion, is not strictly accurate. In ordinary combustion the blast removes the burning gas and combustion ceases, but, in this case, it removes air of low resistance and replaces it by air of high resistance, and also keeps the brushes and commutator cool, and hence the air surrounding them. The arc-light may also be extinguished by a blast of air, and is more nearly a parallel case. But, in the arc, the electric current is maintained after the separation of the carbons by the conductivity of the burning carbon vapor, and the blast extinguishes it by removing this vapor and thus increasing the electric resistance, so that the current cannot traverse the intervening air space; whereas, in sparking at the brushes, there is no combustion or burning vapor, but simply air heated to incandescence.

With the air blast, oil can be freely used to reduce the wear on the brushes without affecting the insulation.

The lightning arrester, used to protect the dynamo against damage by lightning, is also an important adjunct. It is shown in Fig. 29, and is constructed with an electro-magnet, through the coils of which the current between the lamp circuit and dynamo passes. The two magnet cores project vertically above the coils, as shown; and between them are placed, edge to edge, two projecting wings of brass, their broad bases about one-fourth of an inch apart, and their narrow upper parts receding from each other, as shown.

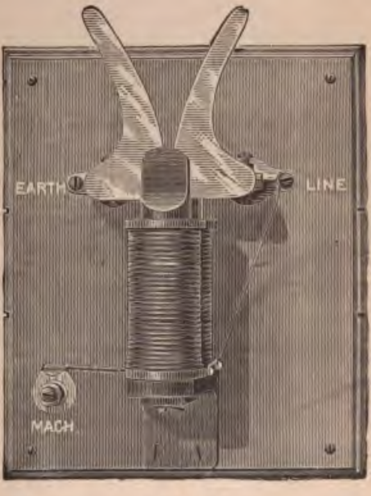


Fig. 29.

The instrument is mounted on a wooden base, screwed to the wall; and the wings are out of contact with the magnet cores, each one screwed to a brass lug, one of which is connected with a line leading to the lamp circuit, and the other with a No. 4 copper wire leading to the earth, as indicated. The line from the dynamo circulates round the magnets, and is also connected to the upper right-hand lug. The lamp circuit line has thus two branches from this lug, one through the magnet to the dynamo, and the other through the brass wings to the earth; the latter interrupted by the narrow, quarter-inch air space at the base of the wings. This air space is sufficient to insulate the left wing from the dynamo current; but if a discharge of lightning occurs on the line, its great intensity causes it to leap the air space, and take the shortest course to the earth; the projecting edges of the wings facilitating the discharge, though not sharp enough to short-circuit the dynamo current. Part of the discharge must go to the dynamo, dividing between the two branches in proportion to the relative resistance of each; but the distribution of this portion in the mass of the machine prevents injurious results.

The object of the projecting magnetic poles, between which the wings are placed, is to extinguish the spark during the passage of the discharge from wing to wing, by establishing a magnetic current at right angles to the line of discharge.

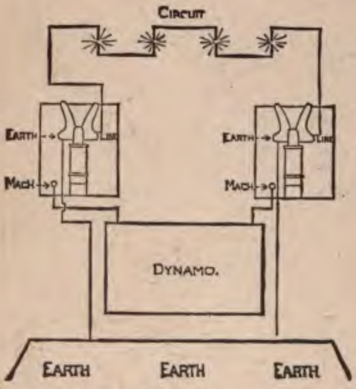


Fig. 30.

Fig. 30 shows the relative positions and connections of the various parts of the system; two arresters, one in each branch of the circuit, being recommended as shown.

Various kinds of arresters are used in connection with different systems of electric lighting, in some of which combs with projecting teeth take the place of the wings, in others a soft metal connection is melted; while in others a mechanical device, operated electrically, severs connection with the machine. These arresters are also applicable to telegraph and telephone systems, and are applied in a similar manner.

THE WOOD DYNAMO.—This dynamo will be readily

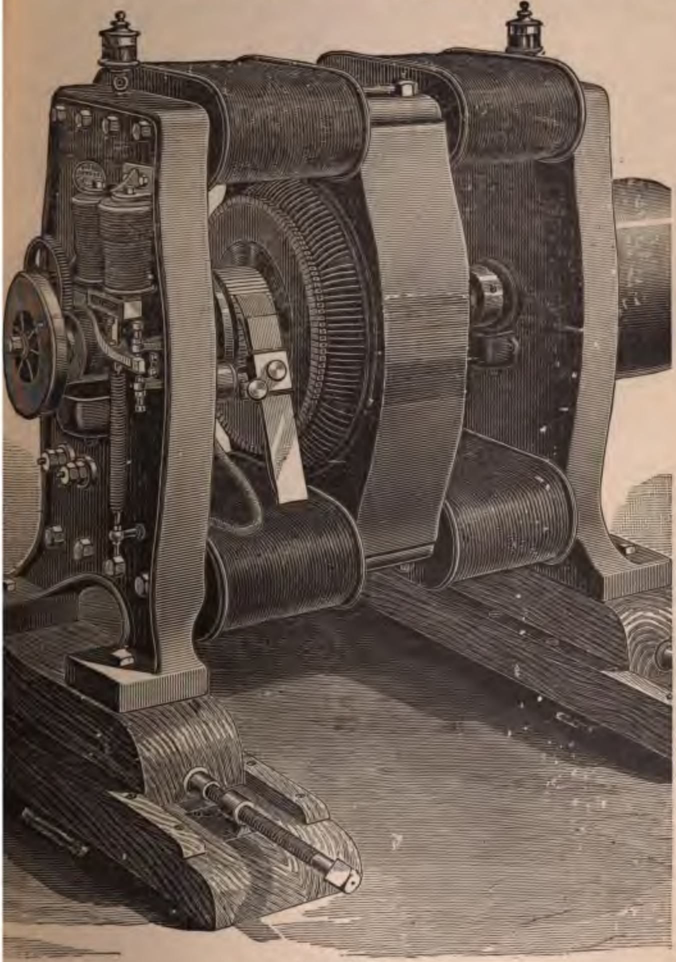


Fig. 31.

understood from Figure 31, without any detailed description. It is of the Gramme type, embracing the features of ventilation of the armature, and autom current regulation, but presenting nothing in its c

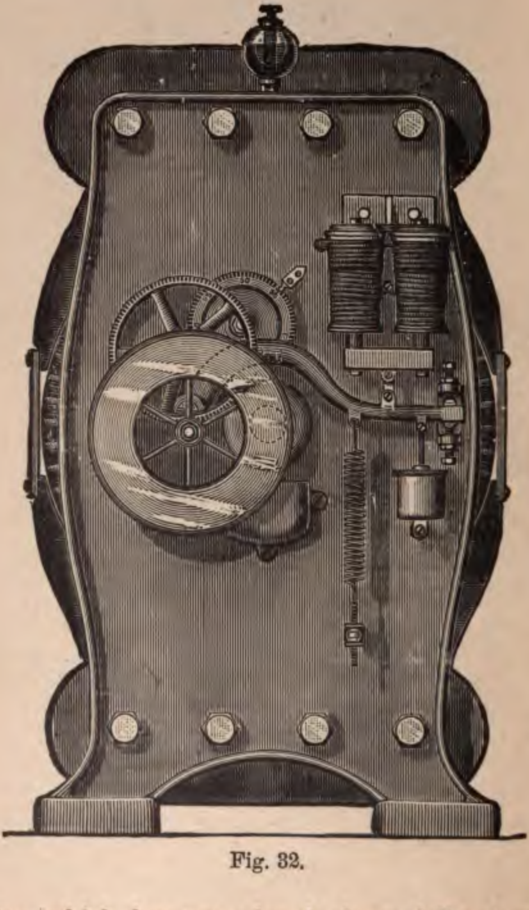


Fig. 32.

struction which has not already been fully describ except the current regulator. This is illustrated *Figs.* 32 and 33. Fig. 32 is an end view of the dynar showing the apparatus in full; and Fig. 33 a side view of the same end, showing the connection with the

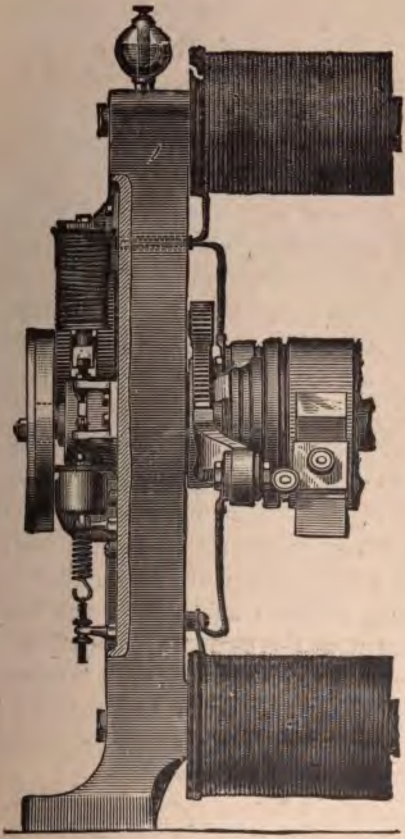


Fig. 33.

brushes; the automatic shifting of the brushes on the commutator to vary the electromotive force being the object to be accomplished. The large friction wheel shown in Fig. 32 has a broad rim with a deep groove on its inner surface next the dynamo. The end of the armature shaft fits loosely into this groove, as shown by the dotted circle on its right side, but is out of contact with the wheel in the normal state of the current. This friction wheel is connected at its centre with the short arm of the curved lever shown in the cut. Above the lever on the right is shown an electro-magnet, connected with the lamp circuit, the armature of which is attached to the long arm of the lever; and below it is a spiral spring which acts against the magnetic attraction. Two stops at the extremity of the long arm limit its movement; and a dash-pot, which consists of a piston moving in a cylinder against air, or other resistance, steadies the movement, and makes it gradual instead of impulsive. A pinion on the hub of the friction wheel engages gearing connected with the yoke to which the brushes are attached, as shown in Fig. 33. The magnetic attraction acting against the retractile force of the spring is just sufficient, in the normal state of the current, to hold the lever in such a position as to keep the friction wheel out of contact with the revolving armature shaft. An abnormal increase of current strength increases the magnetic force, which attracts the armature, and raises the lever, which presses the friction wheel against the revolving shaft on one side of the groove, and by means of the gearing causes the brushes to recede from the neutral line. An abnormal decrease of current lessens the magnetic attraction, the lever is drawn down by the spring, the friction wheel pressed against the opposite side of the groove, the motion reversed, and the brushes made to approach the neutral line.

THE GENERAL ELECTRIC COMPANY'S MULTIPOLAR DYNAMOS.—The General Electric Co. makes two different kinds of multipolar dynamos for direct connection with the source of power, distinguished chiefly by the structure of their armatures; one kind having *iron-clad* armatures, and the other kind *smooth-body* armatures; the field-coils in each being either shunt wound or compound wound.

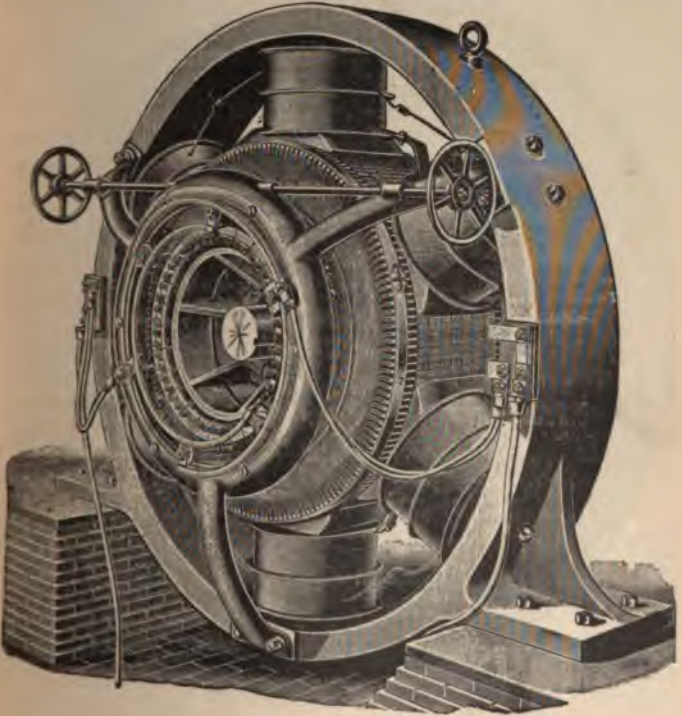


Fig. 34.

Fig. 34 represents the kind having the ironclad armature. This armature, shown separately in Fig. 35, is of the drum type. Its core is laminated in the usual manner, described on page 16, but the insulation consists simply of japanning on the iron, instead of paper between the disks.

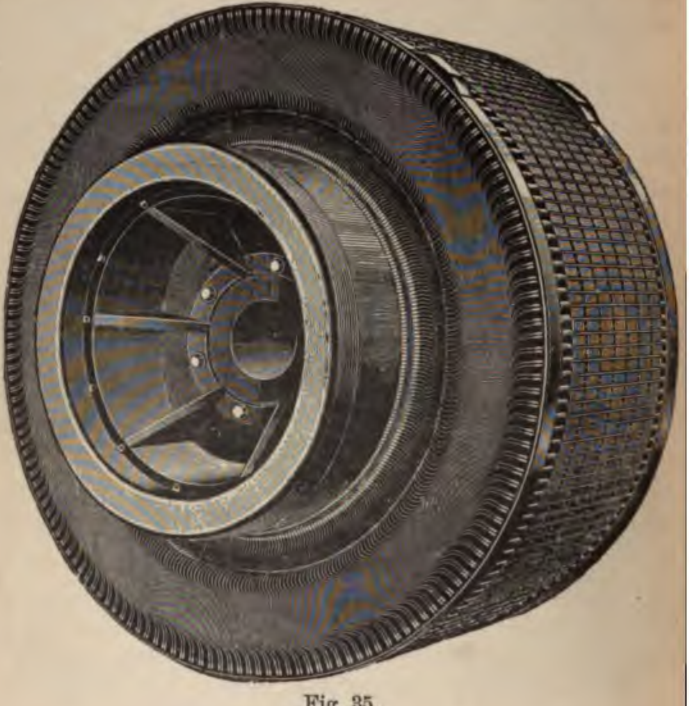


Fig. 35.

The armature winding consists of heavy bars of copper imbedded in slots on the face of the core; each bar being connected with one of the bars next it at one end, and with the other at the opposite end, so as to form a single *continuous* coil, wound back and forth between the core *teeth and round* their alternate, adjacent ends. This coil is insulated with alternate layers of mica and tough paper, and its convolutions are connected with the commutator segments by flexible copper strips in the usual manner. The armature is ventilated as usual, by air spaces between groups of the core disks, which connect with interior tubular openings.

The commutator is mounted on a spider, which is bolted to the interior body of the armature, as shown; and, in the larger sizes, the clamping ring, which holds the segments in place, is made in sections, so that all the segments can be secured with equal firmness, and any section can be removed to make repairs, without disturbing the others.

The field-poles, six to twelve in number according to the size of the machine, are bolted to a circular yoke from which they converge toward the armature, as shown, terminating in broad pole-pieces extended on each side of the coils. In the machine here represented, they are compound wound, and the coils are divided into two sections on each pole, as shown. The series coils are on the inner sections, and consist of insulated copper ribbon, as shown by the connecting terminals between those sections. The shunt coils occupy the outer sections, and also cover the series coils on the inner sections, and are composed of wire, as shown.

The brush-holders are mounted on a spider connected with apparatus by which the brushes can all be shifted simultaneously on the commutator by turning one of the hand-wheels shown, and in the larger machines they can also be lifted simultaneously off the commutator by turning a similar wheel, not shown in this cut.

The brushes are of the type known as metal gauze, and consist of fine wire woven into gauze, and pressed

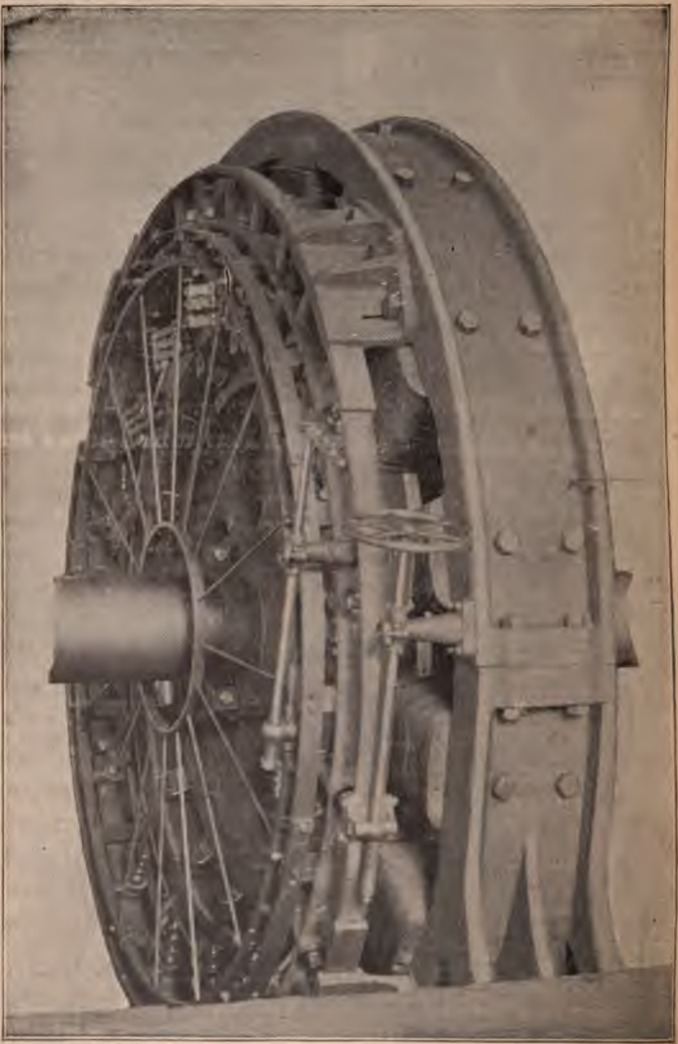


Fig. 36.

into the proper shape for brushes. Copper gauze is largely used for this purpose, but gauze made of other metals is also used, phosphor bronze gauze being preferred for the brushes of these machines. These brushes are noted for their softness, flexibility, and conductivity.

Fig. 36 represents the machine having the smooth-body armature. This armature, shown separately in Fig. 37, is of the ring type. Its core, supported on a spider, as shown, is laminated and insulated as in the ironclad armature. Its winding consists of a single, continuous coil, constructed of heavy bars of copper, wound spirally round the core, and insulated by mica and paper, ventilating spaces being left between the convolutions, connecting with similar spaces between the core rings.

The commutator is an integral part of the coil itself, being composed of the vertical bars on each side of the ring, the outer faces of which, with the insulating material between them, are turned perfectly smooth for this purpose, after the winding is completed. This gives two commutators, one on each side of the vertical face of the ring, and when one becomes too much worn for further use, the position of the armature can be reversed, and the one on the opposite face used. The wear is so very slight however, that this is not required for several years.

The position of the brushes on this commutator is shown in Fig. 36, and being all in plain sight, they are more easily inspected than those on a horizontal commutator. The same arrangements are made for shifting and lifting them simultaneously as in the other machine, and they are constructed of the same material.

The field-coils of this dynamo are all connected with the main circuit in parallel; the two terminals of each coil being attached to two large wires connected with the two branches of the main circuit; so that the circuit flows across from one wire to the other, in each coil separately, and not from coil to coil in series. This method gives much lower E. M. F. than the series method, and proportionately increases the volume of the current.

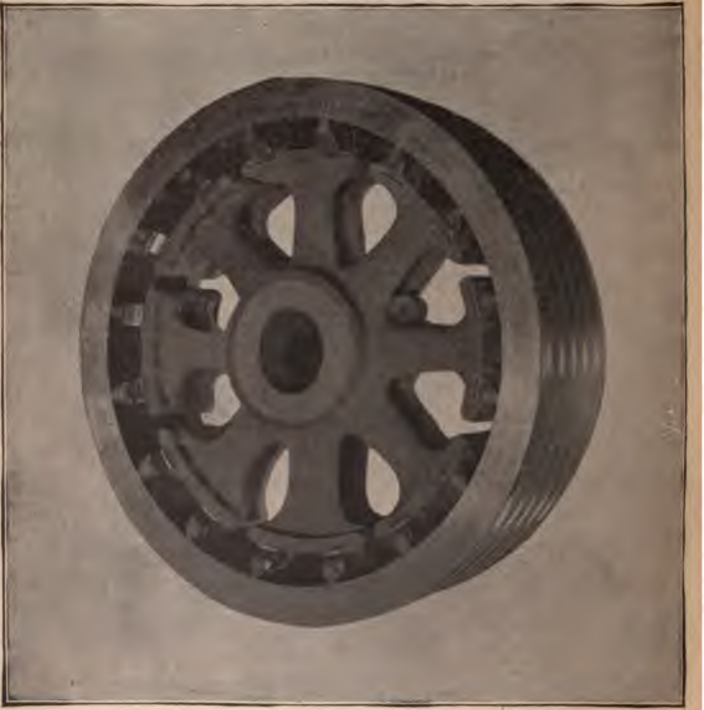


Fig. 37.

The pole-pieces, field-cores, and connecting yokes, in both these dynamos, are made of soft cast-steel of the *highest* magnetic permeability. The smooth-body armatures are employed for machines of the largest size, and the ironclad armatures for the intermediate and smaller sizes.

In the installment of direct-connected machines of either kind in central stations where steam power is employed, economy of space is effected by running two large dynamos of the same kind by an upright steam-engine placed between them; the armatures being mounted on opposite ends of the engine shaft, and taking the place of the flywheel; thus also employing for useful work the power usually consumed in starting the flywheel and maintaining its momentum. There is also an advantage in the perfect uniformity of action obtained by running two dynamos of the same size in this way, in the three-wire system of electric lighting described hereafter.

THE SIEMENS-HALSKE DYNAMO, TYPE I.—Fig. 38 shows the latest improved dynamo of the Siemens and Halske Electric Co., the construction of which differs materially from that of most other dynamos now in use; leading methods of construction common to other dynamos being reversed. It is a series wound, multipolar machine, having four to twelve field-poles; the size shown in Fig. 38 having twelve, six north poles alternating with six south poles, and generating electric energy represented by 1000 horse-power.

These poles instead of being attached to an external yoke and radiating inward toward the armature in the usual manner, are attached to a central sleeve mounted on the armature shaft, and radiate outward toward the armature. Their cores are composed of soft wrought-iron, wound, as usual, with insulated copper wire, and furnished with pole-pieces, rounded as shown, to prevent

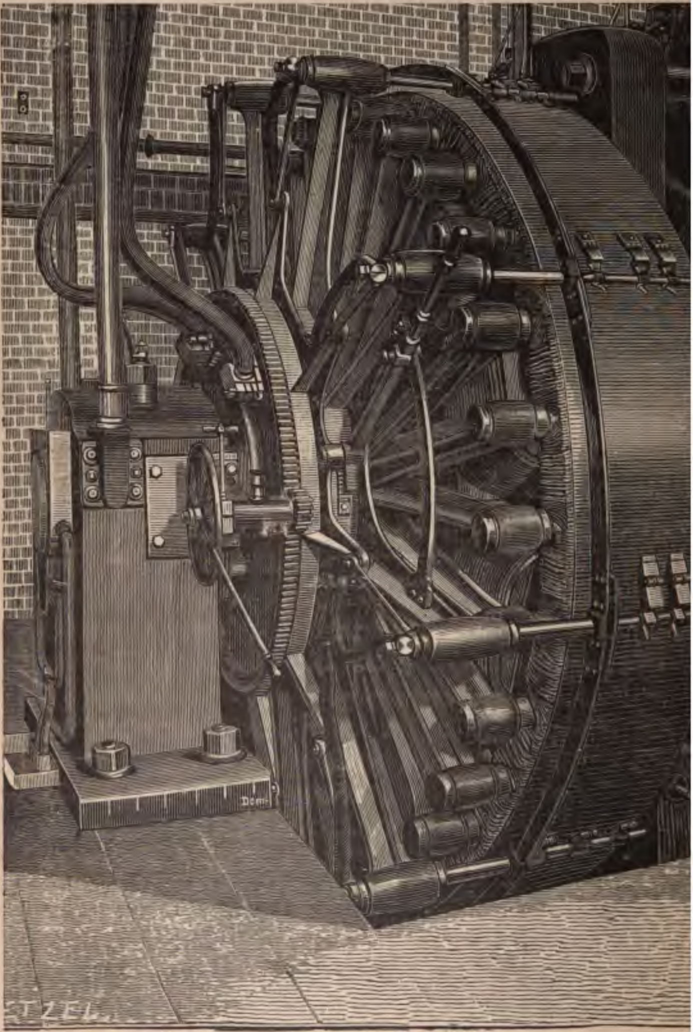


Fig. 38.

magnetic leakage. This construction reduces the magnetic resistance of the field-magnet yoke to the minimum, by furnishing the shortest possible magnetic circuit between the poles, and thus materially reducing the energy required to excite the field magnets.

A ring armature of the Gramme type incloses the field-magnets, instead of being inclosed by them in the usual manner. It is mounted on a spider the arms of which radiate from a central shaft, and have tranverse arms attached to their outer ends, at right angles, on which the armature is supported as shown. Its core is laminated in the usual manner, being composed of segments of sheet-iron perforated with holes for the supporting arms to pass through, and lapped at the ends; the rings thus formed being insulated from each other with paper, and bound firmly together with nuts screwed to the ends of the arms.

The winding of this armature consists of copper bars of this shape ⎵, placed on the inner surface of the core, the two short spurs projecting outward on each side, and being connected in series with the commutator bars which are placed on the outer surface. These spurs are attached to opposite ends of adjacent commutator bars, so as to form a single, continuous, spiral winding all around the armature ring.

In making these attachments the ends of the commutator bars are slotted, and the ends of the spurs fitted to the slots, the projecting ends of the spurs being then bent down on the commutator bars, the joints soldered, and the surface of the commutator made smooth in a lathe. Any commutator bar requiring to be repaired, or replaced by a new one, can be removed by unsoldering the joints, without disturbing the other bars.

Both the spurred bars and the commutator bars are thoroughly insulated from each other with mica, asbestos, and fiber; and ventilating spaces about $\frac{3}{64}$ of an inch wide occur between the spurred bars. The entire coil is made of the finest, hard-pressed copper.

This construction reduces the potential difference between the commutator bars to the minimum, and thus prevents sparking at the brushes and consequent injury to the commutator by burning. It also reduces the electric resistance of the armature to the lowest limit by the use of a single, massive coil, containing a much greater quantity of copper on this large external armature than can be used on an internal armature. A most important result of this reduction of resistance is the corresponding reduction of the heating effect to the minimum; and this is further facilitated by the exposure of more than two-thirds of the coil's surface to the air, and by the ventilating spaces between its internal bars. So that it is quite impossible for this armature to become overheated, or to burn out, as sometimes happens to armatures closely wound with numerous coils and layers of small cotton-covered wire.

As the generation of electric energy is proportional to the number of lines of magnetic force in the field cut by the armature coils per unit of time, it is evident that high speed of the armature coils is essential to the generation of high electric energy. This speed is obtained in armatures of the usual construction, having a limited circumference, by a high rotary speed of the armature shaft; but by the greater circumference of this armature, the same result is accomplished at a proportionally reduced speed of the shaft, the velocity of the coil remaining the same. For instance, in an armature having a circumference of 9 feet, and rotating at the rate of 1200 revolutions a minute, any section of the armature coils would pass a fixed point at no greater speed than in an armature having a circumference of 36 feet and rotating at a rate of 300 revolutions a minute. Reduction of speed is also obtained by the multipolar construction, electric generation varying approximately as the number of poles.

This comparatively slow speed of rotation permits the direct connection of the armature shaft to the shaft of a slow-speed steam-engine or other motor by which the rotation of the armature is produced, without the intervention of a belt, with its cost of maintainance, and the slipping which produces unsteadiness in the electric light.

The magnetic attraction of the interior, fixed field-magnets, acting in opposition to the centrifugal force of the exterior, rotating armature, tends to prevent displacement of the armature's parts, thus giving this construction an important advantage over that of an interior, rotating armature and exterior, fixed field-magnets, in which the magnetic attraction acts in the same direction as the centrifugal force.

It is claimed that the magnetic leakage in a dynamo whose armature incloses the field-poles, as in this case, is much less than in one whose armature is inclosed by the field-poles in the usual manner, since the magnetic lines of force are more closely confined to the field through which the armature coils rotate.

There are twelve sets of brushes, one set for each field-pole. These are mounted on the arms of a spider similar to that which supports the armature, and these arms radiate from a central sleeve which has a limited rotation on the armature shaft. This sleeve is connected with gearing operated by a lever, as shown on the left in

Fig. 38, and the brush-holders are supported in proper position over the commutator by a light circular yoke, as shown; the positive brushes being insulated from the negative. Hence, by a movement of the lever, all the brushes can be moved simultaneously on the surface of the commutator, to or from the neutral lines, to any required distance, till each set occupies, if necessary, the position previously occupied by either of the adjacent sets.

The brush-holders are also connected with the hinged arms of another spider, which radiate from a sleeve on the shaft, and are so arranged that by the movement of a lever connected with a rack at its lower end, as shown at the right of the lever already referred to, all the brushes can be lifted off the commutator simultaneously, by a rotary movement of the brush-holders at a small angle. Carbon brushes are preferred to copper for machines of high E. M. F.

The armature shaft extends a short distance beyond its outer bearing, and this bearing, with the attached brush-holder apparatus, can be slid outward to the end of the shaft, on sliding ways on which it is mounted, allowing the armature to be moved away from the field-magnets, and thus exposing every part of the dynamo for examination and repairs.

CHAPTER IV.

ALTERNATING CURRENT DYNAMOS.

THUS far we have confined our attention to the direct current dynamo; but in certain departments of electric lighting, the alternating current dynamo is preferred, hence its description here is of importance. Fig. 39 is a fair illustration of the style of construction as found in several machines of this class, and shows the typical points of difference between these dynamos and those we have been considering. Here it will be seen that both the armature and the field-magnets are composed of a number of coils, wound on bobbins, and attached to the circumference of circular supports. In the cut the supporting ring and also the bobbins are omitted from the armature, the coils alone being shown, so as to give a better illustration of the movement of the currents. The planes of the armature coils are parallel with those of the field-magnets, and the direction of rotation parallel to the planes of the coils, the axes of the coils being parallel to the axis of rotation.

By reference to Fig. 39 it will be seen that the north and south poles of the field-magnets alternate in position, opposite poles facing each other in the usual manner. As this causes a reversal of direction in the lines of magnetic force between each alternate pair of magnets, a corresponding reversal of current is produced in each alternate coil, as shown by the position of the arrows; and as these opposite currents would neutralize each other, this again is compensated by a reversal in the winding; the wire, as it leaves the bottom and front face of one coil, being led over to the top and rear face of the next coil, so that the momentary armature currents, generated as the coils simultaneously pass the field-magnets, all flow in the same direction, as shown by the arrows between the

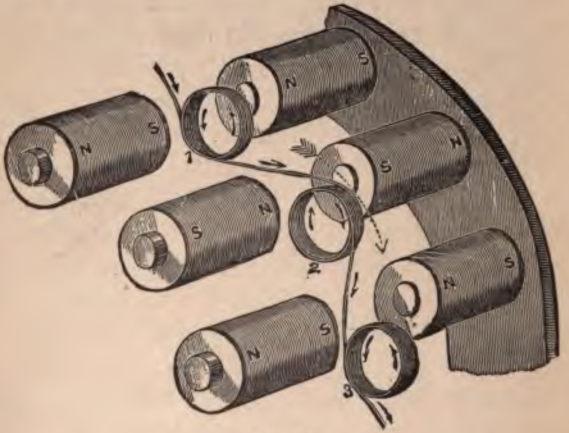


Fig. 39.

coils, while at the next instant this current is reversed, as the rotation changes the position of the armature coils. So that, following any one coil as it rotates, there occur as many reversals as there are pairs of field-magnets.

Instead of the commutator these machines have a collector similarly placed, as shown in Fig. 40, consisting of two flat metal rings, mounted on the shaft, and insulated from each other. To these are attached the two *terminals* of the wire composing the coils, as shown and each transient current generated passes into the outer circuit through the brush which presses on one ring, and is returned through the brush which presses on the other ring, traversing the outer circuit and armature coils in the direction indicated by the arrows at one instant, while at the next this direction is reversed, as already explained.

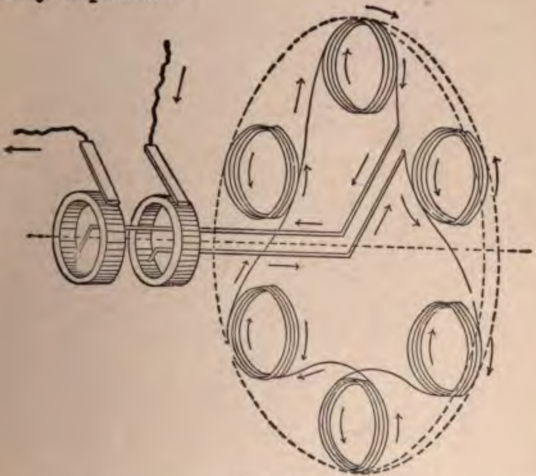


Fig. 40.

There are two methods of connecting the armature coils in alternating current dynamos, known respectively as the series and the parallel. These are illustrated in Fig. 41, the series method at *A*, and the parallel at *B*. In the series method it will be seen that the current flows from coil to coil by a single wire; while in the parallel method the ends of each coil are joined to two separate wires, and the current divided between them. The series method gives the greatest E. M. F., or electric pressure, and also the greatest internal resistance; while in the parallel method the internal resistance is reduced, and the volume of current increased in the same ratio. This becomes apparent when we consider that since resistance in a conductor is inversely as the area of its cross-section, doubling the number of wires, if of the same size, doubles this area, halves the resistance, and doubles the volume of current. Hence if, in electric lighting, large current and small pressure are required, the parallel method is preferred; while if high pressure and small current are required, the series method has the preference. In both methods the alternate coils are wound in opposite directions for the reason already given, as shown in Fig. 40.

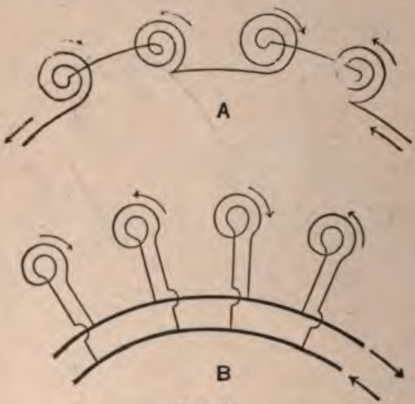


Fig. 41.

THE WOOD SINGLE PHASE, CONSTANT POTENTIAL ALTERNATOR.—The construction of this dynamo, as illustrated by Fig. 42, shows an external, stationary field-magnet having a number of poles radiating inward from a circular yoke, and inclosing a rotating armature. Its field cores are made of laminated iron, cast into an iron *yoke, and* are wound with two sets of coils insulated from

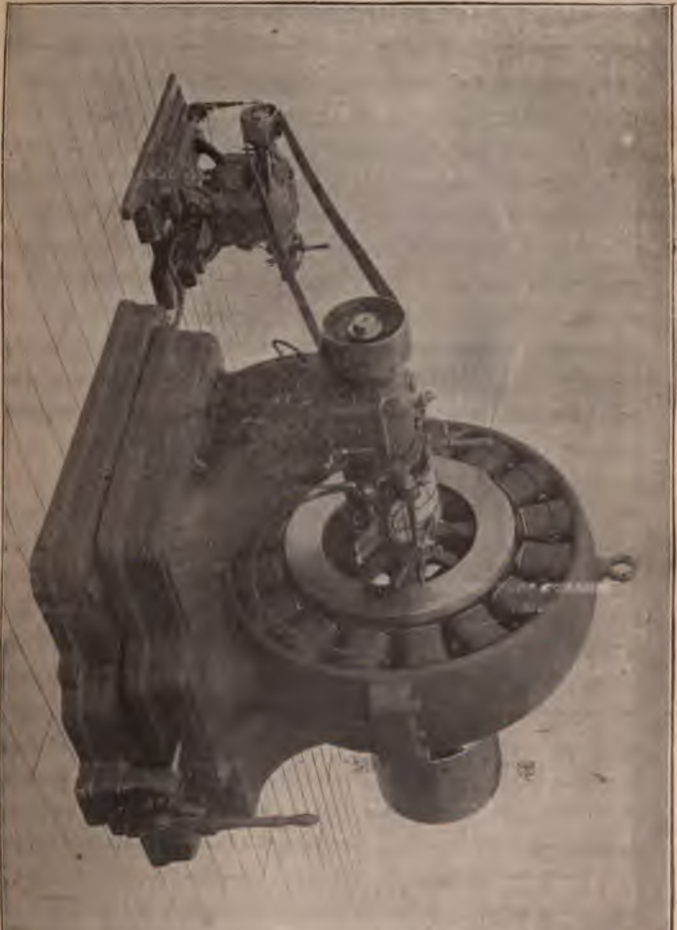


Fig. 42

each other; a fine wire set traversed by a current from a direct current exciter dynamo, shown on the left, and a coarse wire set traversed by a current from the armature, made direct by a commutator. The coils in both sets are wound in the same direction, the coarse wire coils over the fine wire coils, the winding alternating in direction on alternate poles, so as to produce alternate reversal of polarity. The winding is done on a lathe before the coils are placed on the cores, and the proper connections made subsequently; and they are held in place by cleats and screws.

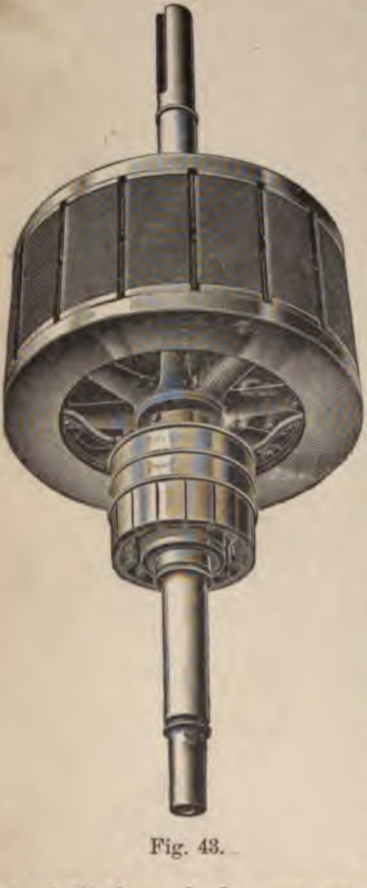


Fig. 43.

The armature, shown in Fig. 43, is of the cylinder type, and its core is composed of C-shaped, sheet-iron rings, mounted on a bronze spider without insulating material between them, and so placed that the open spaces in the rings shall be distributed all through the core, so as to produce ample ventilation. The outer edge of each ring is divided into a number of T-shaped teeth, which are placed in line, opposite each other, in the several plates, when the core is constructed; and the coils are wound under the flanges of these teeth, and secured in place by wooden wedges driven between them, making the armature ironclad, the coils being completely covered by the iron, except at the ends, where they are covered with bronze caps.

The coils are composed of insulated copper ribbon, and are wound in two sets, those of each set being placed on separate, alternate teeth and connected together in series, and the two series connected together in parallel; the winding alternating in direction, as in the field coils, so as to produce alternate reversal of polarity.

In Fig. 42 are shown two collecting rings on the left of the armature, and on the left of these, a commutator, all insulated from each other. The commutator is divided into two sections by connecting together alternate segments, all the evenly numbered segments constituting one section, and all the oddly numbered segments the other section, as described on pages 109,110. There is also a set of German silver resistance coils, shown in Fig. 44, which is inclosed in the front pedestal and covered by the perforated screen shown in Fig. 42, which furnishes it with ample ventilation. These coils are connected with the main circuit by a shunt circuit, as shown by the flexible conductors terminating at the top of the screen, and are traversed by a small part of the main current.

The two terminals of the coarse wire field-circuit are connected with the two commutator brushes, and the two terminals of the external circuit are connected with the two collecting ring brushes, as shown in the diagram, Fig. 45. One terminal of the armature circuit is connected with the right collecting ring, and the other terminal with one section of the commutator, the other section of the commutator being connected with the left collecting ring.

Hence the course of the current, at a given instant, is from the armature to one section of the commutator, thence through the brush in contact with this section to the field circuit, where it divides, and having traversed the coils on opposite sides of the field in two parallel currents of equal volume, and the two having united at a point diametrically opposite to that at which they separated, the current returns to the brush in contact with the other section of the commutator, and from this section it passes to the left collecting ring, and thence out through the external circuit, and back to the right collecting ring, and thence back to the armature.

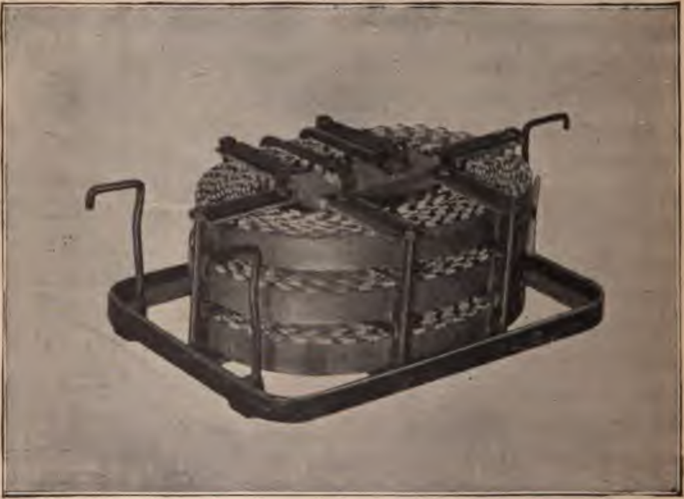


Fig. 44.

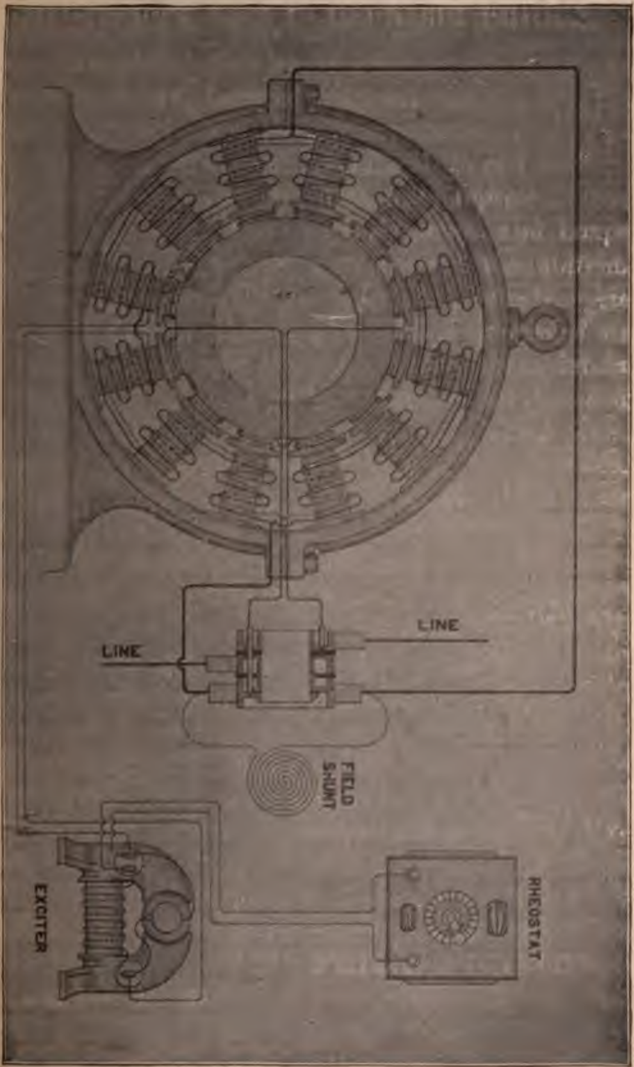


Fig. 45.

The direction of the current being reversed, the next wave passes out from the armature to the external circuit through the right collecting ring and brush, and having traversed this circuit in the opposite direction to that of the previous wave, returns to the left collecting ring and brush, and thence to the section of the commutator connected with this ring. The relative positions of the two commutator sections having been reversed at the same instant that the direction of the current was reversed, the current returning from the external circuit enters the field circuit by the same brush through which it entered before from the armature, and therefore traverses the field circuit in the same direction as before, returning to the armature by the other commutator brush and section.

Hence it will be seen, that while the current traverses the external circuit alternately in opposite directions, it traverses the field circuit constantly in the same direction; entering it, at one alternation, direct from the armature, *before* traversing the external circuit, and, at the next alternation, *after* traversing the external circuit; always circulating through the coarse wire field circuit in the same direction as that of the exciter current which circulates through the fine wire field circuit.

As the volume of current traversing the coarse wire field circuit in this manner varies inversely as the resistance in the external circuit, and this resistance varies inversely as the work, it is evident that the excitation of the field by this current, and hence its E. M. F., or potential, is constantly kept proportional to the work done in the external circuit, as explained on page 111. The exciter current, which traverses the fine wire field circuit, *passes through* a rheostat, which is simply a set of German silver resistance coils with a regulating switch; and by varying the resistance of this circuit in this instrument, the volumes of the current, and therefore the potential of the field due to this current, can be varied as required.

The self-induction of the current, that is, the mutual induction on each other of adjacent convolutions of the coils which it traverses, both in the armature and field circuits, generates an abnormal degree of E. M. F., producing what is known as the *extra current* at the instant the circuit is partly interrupted at the commutator brushes, as they pass from one segment to another. This abnormal E. M. F. and current would produce a rapid succession of bright sparks at the brush contacts which would heat and injure the commutator unless suppressed; hence it was found necessary to introduce the shunt circuit, already referred to, through which sufficient current is diverted from the field circuit to correct these injurious effects, reducing sparking at the commutator brushes to the minimum. This shunt current is only a small part of the main current, as has been stated, and can be adjusted to its proper quantity by varying the number of resistance coils included in the shunt circuit.

As the exciter is belted to the armature shaft of the alternator by the band-wheel on the left, as shown, the relative rate of speed, and therefore of electric generation, must be constantly in the same proportion in the two machines; any variation of these in the alternator producing proportional variation in the exciter, the two being practically constituent parts of the same apparatus.

The terminals of the external circuit are connected to the two binding-posts shown at the base of the front pedestal.

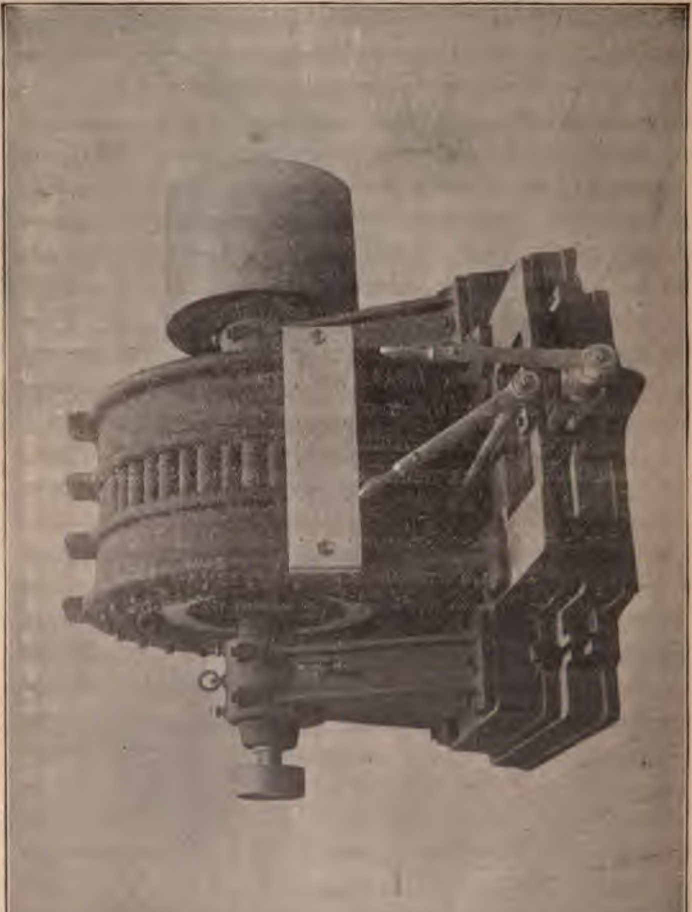


Fig. 46.

THE STANLEY TWO-PHASE ALTERNATOR.—The construction of this dynamo is essentially different from that of any dynamo previously made. It is specially designed to supply the demand for machines which can generate electric current adapted both to electric lighting and the operation of alternating current motors, and belongs to that class of alternating current generators known as *two phase*, which generate two distinct series of current waves, or impulses, each impulse rising to its maximum energy while the preceding impulse falls to its minimum energy; thus producing an alternation in the *phase* of the current, or mental conception of the impulse as a wave, in addition to the alternation in its direction as ordinarily generated; the phase alternation specially adapting it to the requirements of the alternating current motor without interfering with its adaptation to electric lighting.

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By referring to Fig. 46, it will be seen that the generating part of the machine is divided into two distinct sections, on the right and left of a central space, both constructed in exactly the same manner. The external, stationary part, in both sections, represents the armature, and the internal, revolving part, represents the field-magnet, preferably called the *inductor*, in this machine.

The armature core is composed of sheet-iron laminæ, bolted together without insulation between a pair of cast-iron standards, in each section; the bolts extending across through both sections, as shown in the central space. The interior surface of the core, as shown in Fig. 47, is divided into a number of polar projections, by grooves in which the coils are placed. The coils are composed of insulated copper wire, and are wound separately on forms, in rectangular shape, curved to correspond with

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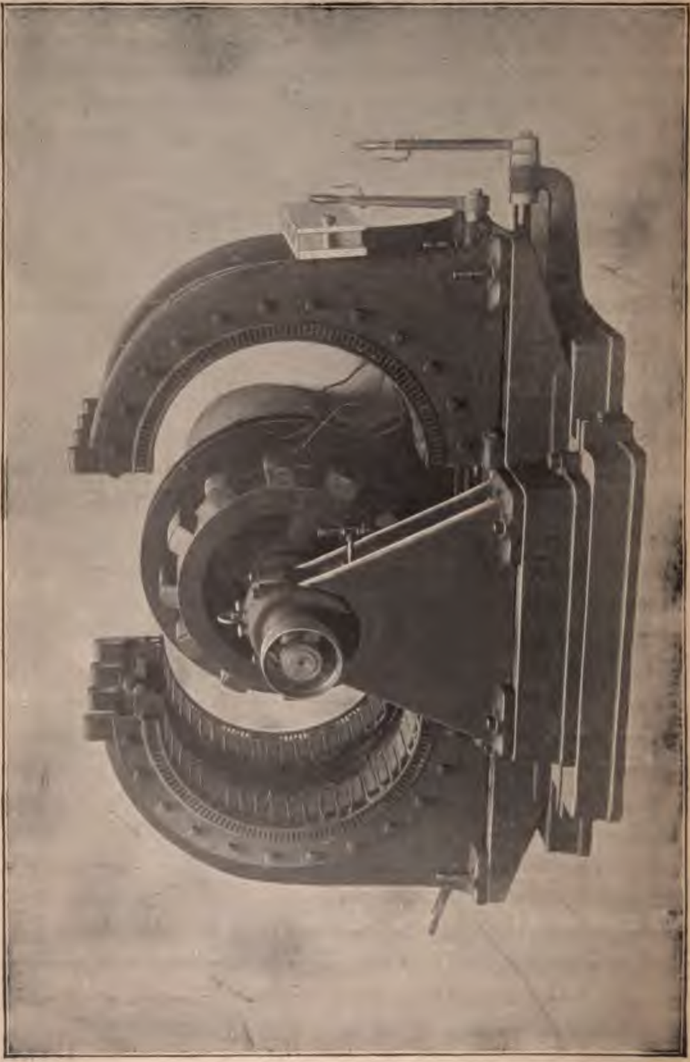

Fig. 47.

the curve of the core, and are covered with insulating tape before being placed in the grooves, and secured in place by brass clamping rings.

The armature is divided into halves, horizontally in the small machines, and vertically in the large ones, as shown in Fig. 47, for convenience in setting up and making repairs; and each half contains four sets of coils, making eight sets in all, two in each of the four sections produced by this subdivision. The coils in each set are wound alternately in opposite directions and connected together in series, and the sets may be connected together either in series or in parallel, as explained hereafter.

Each coil incloses two core projections, as shown; one set being placed over the other set in each of the four sections, in such a manner that two opposite sides of each coil in the upper set rest on the centers of two adjacent coils in the under set, as shown. The effect of this arrangement is to produce the two phases of the current already mentioned, each phase beginning at one edge of each coil, under the influence of the field-magnet, or inductor, and reaching its maximum at the center; so that the phase in one set of coils has reached its maximum, at the instant the phase in the other set, either upper or under, has reached its minimum. The four upper sets are connected together, either in series or in parallel, and likewise the four under sets, but the upper and under sets have no electric connection whatever with each other.

The field-magnet, or inductor, is shown in Fig. 48. It is made in two sections, identical in construction, and corresponding in width and position to the two sections of the stationary armature, within which it rotates. Each section consists of a set of polar projections of laminated

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iron, without insulation between the laminæ; all the north poles of one set facing all the south poles of the opposite set; so that the alternation of direction in the armature current is not produced by alternation of polarity in the field-magnet, but by alternation in the direction in which the armature coils are wound. These polar projections are mounted on a circular, steel casting, supported on the shaft by a steel spider, and having flanged clamping rings at the ends and center, between which the laminæ are bolted. The laminæ are held in place by flanges projecting from opposite sides of their bases, which fit under V-shaped flanges on the steel casting. Their upper ends are made slightly convex, and the corners rounded, as shown, to produce smoothness in the phase of the current waves generated in the armature coils as they come within the inductive influence of the field-poles.

There is only one field-coil, and it is wound on a large, circular, copper spool, placed in a fixed position, inclosing the space between the field-poles, and fitting into the space between the armature coils, as shown in Fig. 47. The current which circulates through this coil is employed to excite the field-magnet, and is supplied by a small, direct-current dynamo, or exciter, driven by a small pulley, shown on the left hand of the shaft in Fig. 46; hence this coil is also known as the exciter coil. The spool is made of heavy copper to absorb and eliminate the static charge which accumulates in the coil when opening the field circuit and tends to break through the insulation of the wire; and this is accomplished the more effectually by its inclosing the coil on three sides.

The whole machine is thoroughly ventilated, air being *drawn into* the interior of the field-magnet through the

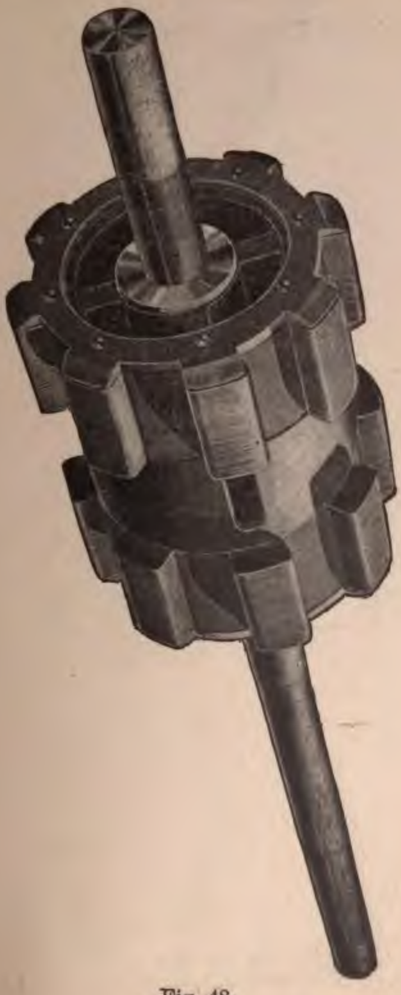

Fig. 48.

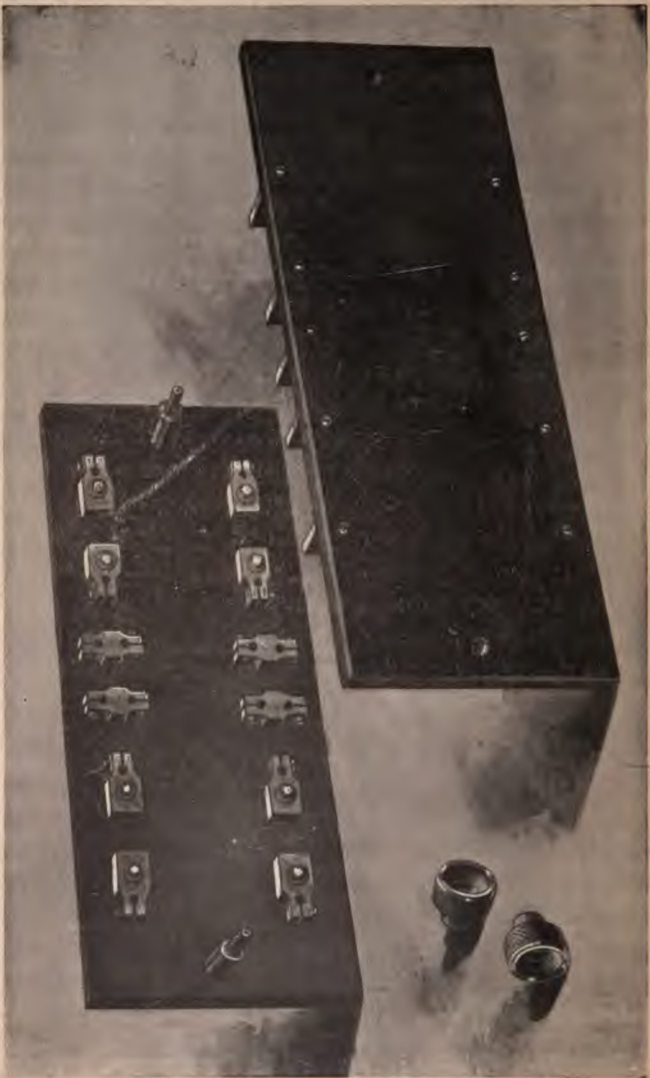

Fig. 49.

spider, and discharged by centrifugal force against the coils through central openings, one of which is shown in Fig. 48, and passes out between the field-poles.

As there are no rotating coils in any part of this machine, sliding contacts constructed with brushes and collecting rings, as in other machines, are not required; the coil terminals being brought out and connected with each other and with the external circuits on an insulating terminal board, shown attached to the machine in Fig. 36, and separately in Fig. 49. This board is constructed with two heavy slabs of marble, bolted together; the inner slab supporting twelve terminals, each of which is inclosed in a separate compartment by partitions on the outer board, when the slabs are bolted together.

It should be carefully noticed that the two phases of the current are produced independently of each other, one phase by the under sets of armature coils and the other phase by the upper sets, as much so as if produced by two separate machines generating currents alternately in phase. The upper sets of coils are connected with a separate circuit from the under sets. Each of these circuits would ordinarily have two lines of wire, four wires in all, parallel with each other on the same poles; but this is not necessary, as a single large wire may be substituted for two of them, thus effecting a saving of about 15% in the amount of copper required for line wire; the central wire being employed to complete a circuit with each of the outer wires, and being 41% larger than either in cross-section. A current wave, transmitted from the upper coils by one of the outer wires, returns to the dynamo by the central wire, and the next wave, transmitted from the under coils by the other outer wire returns also by the central wire; the current being reversed, the two following waves, one from the upper coils and the other from the under coils, pass out successively by the central wire, each returning by the outer wire through which it passed out at the previous alternation.

The lamps are connected with each of these circuits separately, in the same manner as on circuits from single phase dynamos, but electric motors must be connected with both circuits jointly, so that the alternate phases of the current may traverse the motor in accordance with the special design of this dynamo.

When the upper sets of armature coils are connected together in series, and also the under sets, as already mentioned, the E. M. F. in each circuit is double what it is when the connection is made in parallel; but the volume of current, with the parallel connection, is double that with the series connection. These connections are made on the terminal board, and are easily changed from series to parallel, or the reverse, as may be required; any connecton between the upper and under sets being carefully avoided.

In making repairs, the upper half of the armature may be lifted, and the field-magnet removed. This can easily be done in the small machines, whose armatures are divided horizontally for this purpose; but as the weight of the large machines would make this method inconvenient, their armatures are divided vertically, so that the two halves can be drawn apart by screws, as shown in Fig. 47, sliding on removable tables provided for this purpose, and leaving the field-magnet undisturbed.

The construction of the self-oiling shaft bearings, with the loose rings for lifting the oil and distributing it on the bearing, according to the method now in general use, is fully illustrated in Fig. 50. The rings fit loosely in the slots shown in the bearing lining, and therefore rest on the shaft when it is placed within this lining, and rotate with it, bringing up the oil which adheres to them, from the well underneath the lining, and distributing it on the shaft.

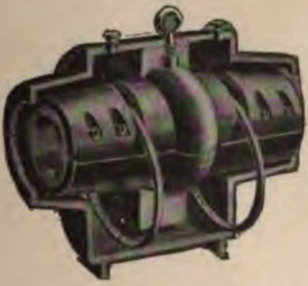

Fig. 50.

The Westinghouse Two-Phase, Constant Potential Alternator.—This dynamo, illustrated by Fig. 51, is similar to the Wood in appearance and in the construction of its field-magnet cores and yoke, supporting base, and relative position of field-magnet and armature, but its electric construction and coil windings are very different.

The yoke is made of cast-iron, in two parts, the upper part being removable, and the pole cores of soft steel, laminated, without insulation or ventilation between the plates, and cast into the yoke. The field-coils are wound on zinc bobbins, bolted to the yoke, and are so connected, in series, that the current traverses them alternately in opposite directions, producing alternate poles of opposite polarity.

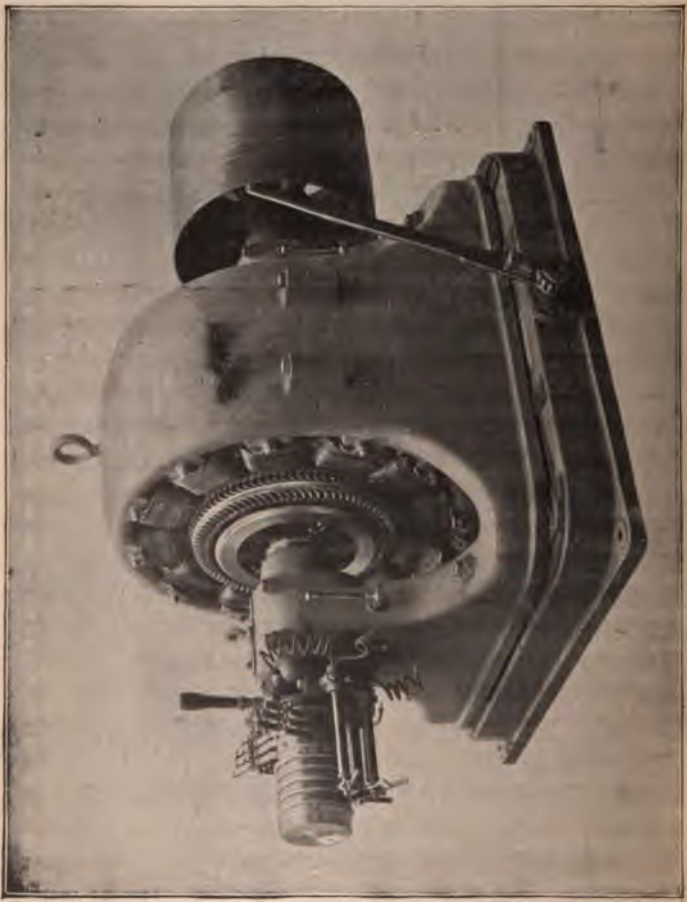

Fig. 51.

armature is of the cylinder type, and has a lami- soft steel core, without insulation between the , but with ventilating spaces at proper intervals. plate is constructed with internal, supporting arms,

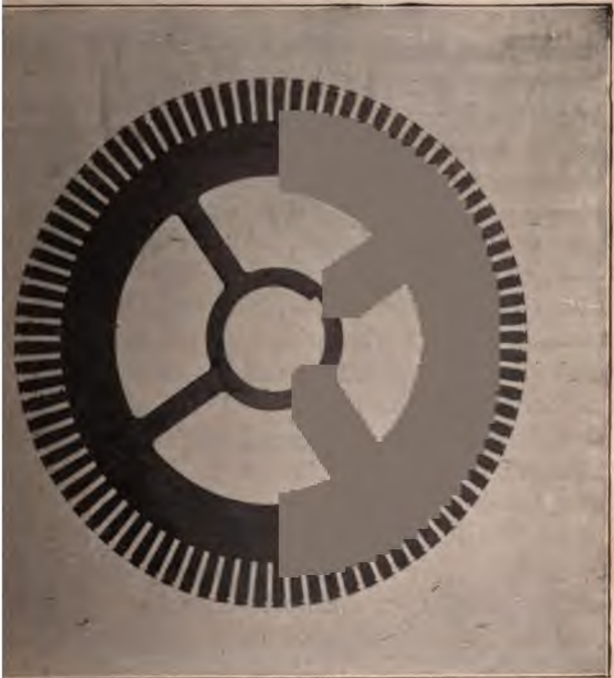

Fig. 52.

xternal teeth, as shown in Fig. 52, and is mounted ly on the shaft and keyed to it; so that the entire including the arms, is laminated, and has ventilat- paces between the arms, connected with those be- the teeth.

The armature coils are made of thin copper bars which fit edgeways in slots between the teeth; each coil consisting of two bars with end terminals, properly shaped and covered with insulating material before being placed on the core. These two bars are separated by several intervening teeth, the slots between which are occupied by the bars of adjacent coils, constructed in the same manner. If, for instance, two bars belonging to the same coil occupy slots 1 and 4, the two bars of the next adjacent coil will occupy slots 2 and 5, and those of the next coil, slots 3 and 6, and so on; the number of coils thus placed depending on the size of the dynamo, several bars occupying each slot. An eight pole armature, for instance, may have 56 coils thus placed, the two bars of each coil being separated by seven teeth, making eight sections in the entire winding; the terminals crossing each other at opposite ends of the core.

When the coils are all placed on the core in this manner, the terminals of adjacent coils are soldered together in such a way as to produce a single, progressive series of coils all wound in the same direction; a terminal of coil 1, for instance, being soldered to a terminal of coil 2, the other terminal of coil 2, to a terminal of coil 3, and so on; the last terminal of the last coil being soldered to the first terminal of the first coil; making a closed circuit armature, like that of a direct current, closed circuit armature. The coils are then secured in place by strips of insulating fiber driven over them in the slots shown in the sides of the teeth in Fig. 52. This closed circuit is then tapped at four points, 90 degrees apart, by four wires, each of which is connected to a separate collecting ring, mounted on the front end of the *shaft; these* four rings being insulated from each other, and divided into two pairs, each pair connected with the armature coils at diametrically opposite points.

The current is collected from each pair of rings by a pair of brushes, each pair connected with a separate, external, two-wire circuit; and each alternate wave, when generated in the coils, traverses them in two circuits, on opposite sides of the armature, from one tap to the opposite tap, where the two unite and pass out by the same ring and brush, returning to the opposite tap by the other ring and brush, after traversing the external circuit.

The effect of tapping the armature coils at four points, as described, is to produce two separate current waves, or phases, derived from the coils at distances 90 degrees apart, which traverse each main circuit alternately in opposite directions; each wave rising to its maximum hight while the preceding wave is falling to its minimum hight. The two external circuits may be constructed with three wires instead of four, in the manner described in connection with the Stanley two-phase dynamo, page 103; in which case only three collecting rings are required, two of the taps being connected to a central ring.

The field-magnet is excited in part by a small, direct current dynamo, and also by a part of the current generated by the armature and made direct by a commutator for this purpose. The latter current is generated by a pair of coils wound on two opposite arms of the four which support the armature core, and the terminals of these coils are extended in grooves on the shaft to the commutator shown near its outer end, on the right of the collecting rings; these coils being entirely separate from those which generate the main current. The segments of this commutator are alternately connected together in two sets, all the evenly numbered segments in one set, and all the oddly numbered segments in another set. Two pairs of brushes make contact with them at points diametrically opposite, and the current waves, alternating in direction as the segments in each set alternate in relative position, all pass out in the same direction by one pair of brushes and return by the opposite pair and are led to and from the field circuit respectively by flexible conductors connected with it on opposite sides, at the base of the front pedestal. The exciter dynamo is connected with the field circuit in a similar manner, and its current traverses the field-coils in the same direction as the other current; the two combined constituting the field current.

The four wires which tap the main coils are wound in coils on the four arms of the armature, two of them beside the pair of coils described above, and are extended thence to the collecting rings. By this construction, these two sets of coils are so related to each other in position that the waves of current, traversing each set independently, are attaining their maximum strength in one set while declining to their minimum strength in the other set, as in the two main circuits.

These two sets, with the cores on which they are wound, constitute an apparatus practically the same as the transformers described at the end of this chapter. When a current traverses either set while there is no current traversing the other set, the self-induction generated between adjacent convolutions of the same coils produces counter E. M. F., which reduces the volume of the current; but when currents traverse both sets simultaneously, in two phases related to each other in the manner described above, the self-induction in each set is neutralized by the inductive influence of the other set, in proportion to the relative strength of that influence in each set respectively, and the volume of current traversing the circuit, or circuits, connected with each set is increased proportionally. Hence, if the main circuits are open and the field circuit closed, the counter E. M. F. due to self-induction will reduce the volume of current in the latter circuit to a comparatively small quantity. But if the main circuits are also closed for the performance of work, as the supplying of current to electric lamps or motors, the counter E. M. F. in the field circuit will be reduced in proportion to the volume of current traversing the main circuits, and hence a current of larger volume will traverse the field, increasing its E. M. F. and magnetism in proportion, approximately, to the work performed in the main circuits.

This process is reversed as the work decreases, because less current flows through the main circuits; the resistance in these circuits always varying inversely as the number of lamps or motors taking current in parallel, and the volume of current varying inversely as the resistance. Hence the E. M. F., or potential, of the dynamo is constantly approximately proportional to the work.

On the left end of the armature shaft is shown a bronze cap which covers the six terminals of the wires connecting with the collecting rings and commutator. Two of the four terminals of the external circuits are shown connected with two collecting ring brushes; also one terminal of the rectified field circuit is shown connected with a commutator brush; the lower end of this wire, when the connection is completed, extends down to the base of the front pedestal, and connects with the field-coils in the little block shown at the right of the bolt head, with which also the terminals of the exciter circuit are also connected as shown.

The shaft bearings are made self-oiling by loose rings in the usual manner, the quantity of oil in the well being indicated by an oil gauge, one of which is shown on the front pedestal. The terminals of the main armature coils are confined by a band as shown, and the interior coils are protected by the bronze ring shown. The exciter is usually belted to a pulley on the engine shaft, but may be belted to one mounted on the armature shaft, outside the main pulley, if desired.

The Converter.—A very important feature of the alternating current system of electric lighting, of which these machines form a part, is the converter, or transformer, which may be described as an inverted induction coil.

The ordinary induction coil is made with two helices insulated from each other: an external helix of long, fine, insulated copper wire, having many turns, incloses a helix of shorter, coarser wire, having comparatively few turns, and this incloses a core composed of a bundle of iron wires. The interior helix, known as the primary, when connected with an electric generator magnetizes the core, which, by reciprocal action, increases the strength of the electric current; and the primary circuit being opened and closed with great rapidity by a circuit-breaker, a series of alternate currents in opposite directions is induced in the secondary circuit; the electromotive force of these induced currents as compared with those in the primary being increased in the direct ratio of the increased number of turns. In such a coil, electromotive force is increased at the expense of current strength, but in the converter, current strength is increased at the expense of electromotive force. This is effected by connecting the high resistance coil with the generator, and the low resistance coil with the lamp circuit, the alternation being produced in the dynamo.

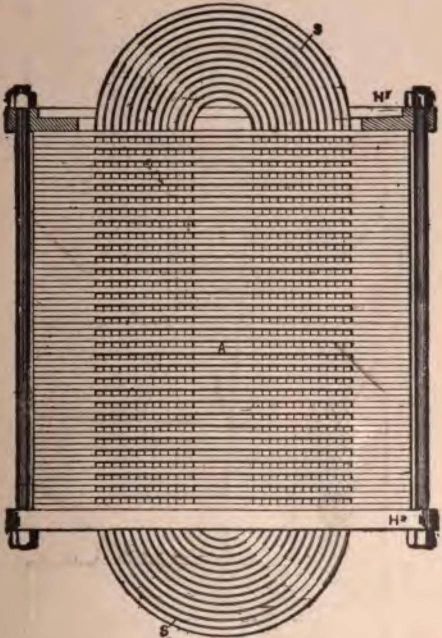

Fig. 53.

In the induction coil, the core, being in the center, is separated from the secondary helix by the interposition of the primary, and hence its magnetizing effect on the secondary is reduced as the square of the distance represented by the thickness of the primary. In the Westinghouse converter this arrangement is partially

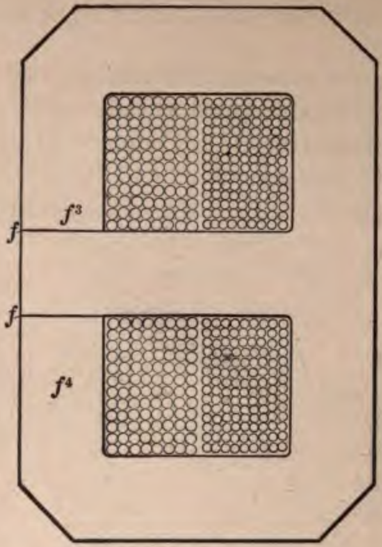

Fig. 54.

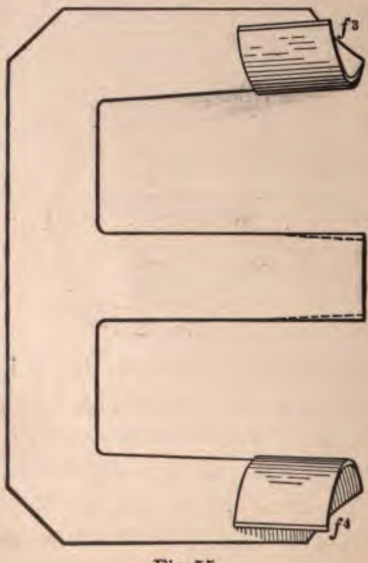

Fig. 55.

reversed, the two coils being placed side by side, and inclosed within an iron envelope which fulfills the magnetizing function of the core, both coils being thus brought into close contact with the iron. This closeness of contact is effected more perfectly by dividing the converter into connected sections having comparatively thin coils instead of using a single large converter requiring great thickness in the coils. The magnetizing envelope is composed of sheet-iron plates, insulated from each other, placed at right angles to the longer

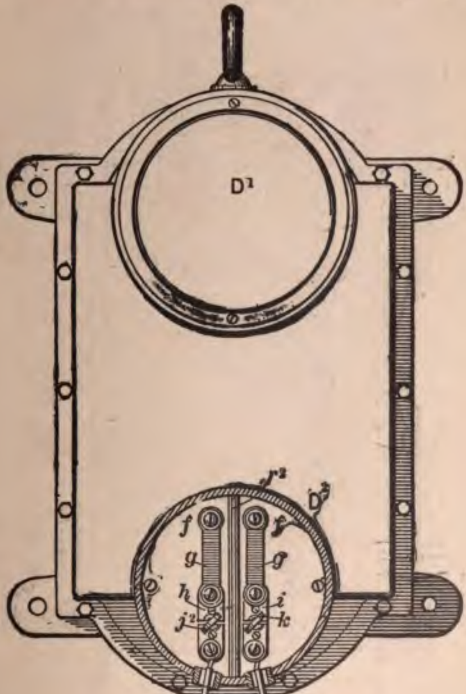

Fig. 56.

axis of the elliptic-shaped coils, built up around them, and bolted together; the proportion of iron in the envelope to that of copper in the coils being as $2\frac{3}{5}$ to 1. The loss from electrical conversion in a reduction from 1,000 volts in the primary to 50 in the secondary is said not to exceed five per cent.

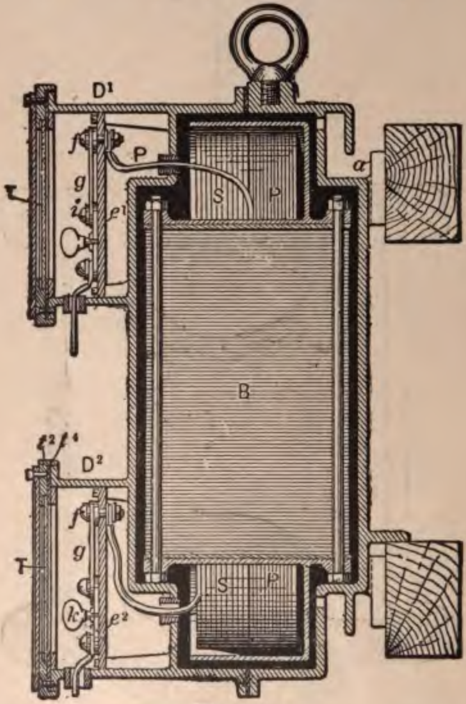

Fig. 57.

Fig. 53 gives a front view of the converter, and Fig. 54 a view in cross-section; the fine wire at the right showing the primary coils, and the coarse wire at the left the secondary; and *f f f f* the magnetizing *envelope; the* edges of its plates being shown at *A*.

The coils, composed of covered wire, and thoroughly insulated from each other and from the plates, are first wound on a form, and the plates, shaped as in Fig. 55, built up around them; the ends, $f_3\,f_4$, being first bent back as in Fig. 55, and then laid flat as in Fig. 54. The plates are then bolted together by means of the end frames, H_1 H_2, Fig. 53, and the apparatus inclosed in the iron case shown in Figs. 56 and 57, by which it is protected from dampness, injury, and accidental contact with electric wires; the cases being arranged for convenient attachment, as shown.

Fig. 56 is a front exterior view of the case, and Fig. 57 a sectional end view of its interior; the terminals and connections of the coils being inclosed in the compartments D_1 D_2, fitted with glass, T T, in front to permit inspection; the primary and secondary being separated from each other in each compartment by insulating plates, as shown at r^2. One terminal of the primary coil is shown at P above, and one of the secondary coil at S below, in Fig. 57; the positions of the other terminals, above and below, being easily understood from Fig. 54. The terminals are attached to the bolts, f f, mounted on the insulating plates, e_1 e_2; g g, being safety fuses, h and i switches, and k and j^2 plugs for opening and closing the connections.

In the more recent construction of transformers, the safety fuses are inclosed in a separate box, which is placed in a position easily accessible for the renewal of a fuse in case one melts, or "*blows*" as technically termed, but otherwise the construction is substantially as here described.

A transformer may be employed to increase the E. M. F. instead of reducing it as described. This is accomplished simply by reversing the use of the coils, employing the coarse wire coil as the primary and the fine wire coil as the secondary. When constructed in this way, it is known as a *step-up* transformer, to distinguish it from the usual construction, in which it is known as a *step-down* transformer.

It is sometimes necessary either to increase or decrease the E. M. F. to a much greater degree than would be practicable by the employment of a single transformer. This is accomplished by employing several transformers connected together in series, the primary coils in one series and the secondary in another, as shown in Fig. 58, where twenty are thus connected together, each being a section of one large transformer.

This requires special construction, the difference between the primary and secondary coils of each section in the relative size of the wire and the relative number of turns in each coil respectively, being far less than would be possible in a single transformer having the same difference of potential as exists between the primary and secondary coils at the opposite ends of this series; the generation of E. M. F. being always in proportion to the number of turns in the coil. And the liability of the electric current to break through the insulation at any point is proportionally reduced in the series by the comparatively low potential difference in each section.

Transformers of this description are employed for long distance transmission, where very high E. M. F. is required; the step-up kind being used at the end of the line where the electricity is generated, and the step-down kind at the end where it is delivered.

Transformers designed for out-door use, mounted on poles and connected with the line, as shown on page 119,

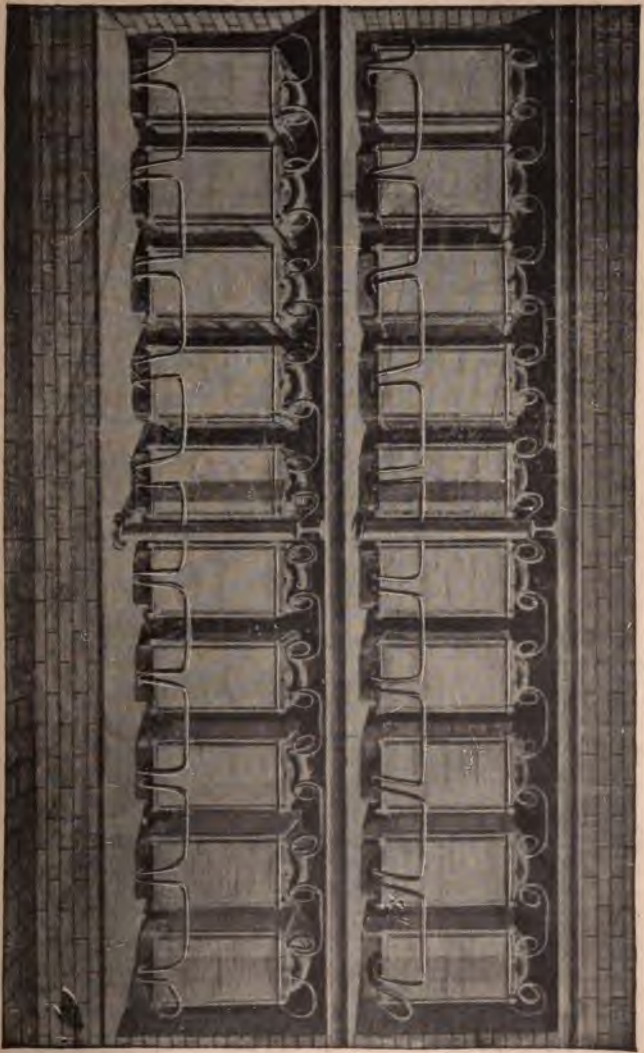

Fig. 58.

require to be inclosed in iron cases to protect them from the weather. One of this kind made by the General Electric Co., is shown complete in Fig. 59, and its interior construction in Fig. 60. Its primary coil is inclosed within its secondary, which brings the secondary into close proximity with the greater proportion of the external iron, and more fully under the inductive influence of the primary coil than when the coils are placed side by side.

The secondary is divided into two separate coils of equal size and the same construction, placed side by side as shown; and these may be connected with the lamp circuit either in parallel or in series. When connected in parallel, the E. M. F. generated is only half that generated in the series connection, since the generation of E. M. F. is in proportion to the number of turns through which the electric current circulates in series, as already stated, and not in proportion to the volume of the current or the size of the wire in cross-section. And in the parallel connection, the effect is the same as if the wire were doubled in size, and had only half the number of coil turns as in the series connection; producing double the volume of current, but only half the E. M. F.

These two different modes of connection are made in a very simple manner, on a connection board made of insulating material and enclosed within the cap shown in Fig. 59. This board is shown at A in Fig. 61, with the connections arranged in series, and at B, with the connections arranged in parallel. It has six copper connection plates with binding-screws attached, and is pierced with holes for the terminals of the coils and of the line circuit and lamp circuit. The two terminals of the primary coil, shown in Fig. 60, are brought up and

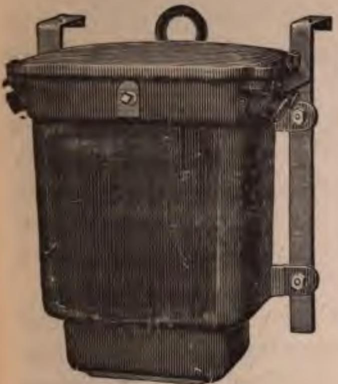

Fig. 59.

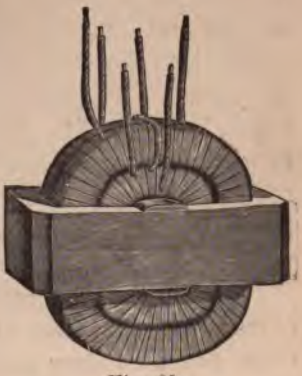

Fig. 60.

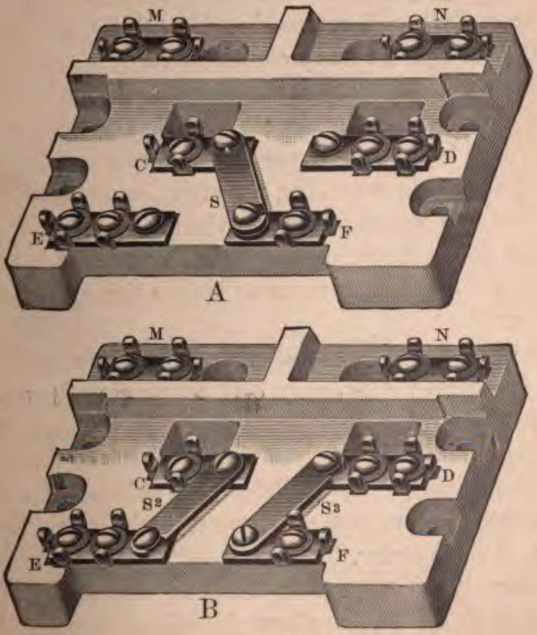

Fig. 61.

attached to the plates M and N by two of the binding-screws, and the two terminals of the line circuit are attached to the same plates by the two remaining binding-screws. The two terminals of one of the secondary coils shown in Fig. 60 are brought up and similarly attached to plates C and D, and the two terminals of the other secondary coil to plates E and F. One terminal of the lamp circuit is attached to plate E and the other to plate D.

In the series connection, shown at A, the secondary current, entering from the lamp circuit by plate E, traverses the secondary coil connecting E with F, passes thence through the switch S^1 to plate C, traverses the other secondary coil connecting C with D, and returns from D through the lamp circuit to E.

In the parallel connection, shown at B, the secondary current from the lamp circuit, entering as before by E, divides, one half of it traversing the coil connecting E with F, and thence passing through the switch S^2 to D. The other half passing through the switch S^3 to C, traverses the coil connecting C with D, and there uniting with the former half, returns as before through the lamp circuit to E.

In both modes of connection, the line current, entering by N, traverses the primary coil connecting N with M, and returns to the line circuit from M. The direction of the current in both circuits and modes of connection has been arbitrarily assumed for convenience of description; hence the current may traverse the same connections in reverse order.

The supply of current to the lamp circuit at different degrees of E. M. F., as above described, is often found convenient, to adapt the current to the requirements of the lamps and lamp circuits, a much higher degree of E. M. F. being required in some cases than in others.

The transformers here described belong to the step-down class; the usual E. M. F. of the line current supplied by an alternating current dynamo being comparatively quite high, and requiring to be reduced, both for safety and adaptation to use, before the introduction of the current into a building.

In the larger transformers of this kind, the coils are usually immersed in mineral oil contained in the lower part of the case, which is an excellent insulator; and in case of the other insulating material being ruptured, by lightning or otherwise, the oil at once flows in and supplies its place, thus restoring the insulation.

Joints being always undesirable in conductors carrying such powerful currents as circulate through these large transformers, the connection boards are dispensed with, to lessen their number; the coil terminals being connected directly to the circuits, through the fuses and switches, at points conveniently accessible outside the case.

THE WESTINGHOUSE ROTARY TRANSFORMER. — The alternating current is capable of transmission to distant points much more economically than the direct current, while the direct is better adapted to certain kinds of work than the alternating. Hence, in the distribution of current from a central station, it is important to have an apparatus which can make the alternating current direct, after transmission, wherever such transformation is required. This is done by the rotary transformer.

The construction of this machine, as illustrated by Fig. 62, is easily understood. It consists simply of a direct current, compound wonnd, multipolar dynamo, whose armature coils are tapped at four points, 90 degrees

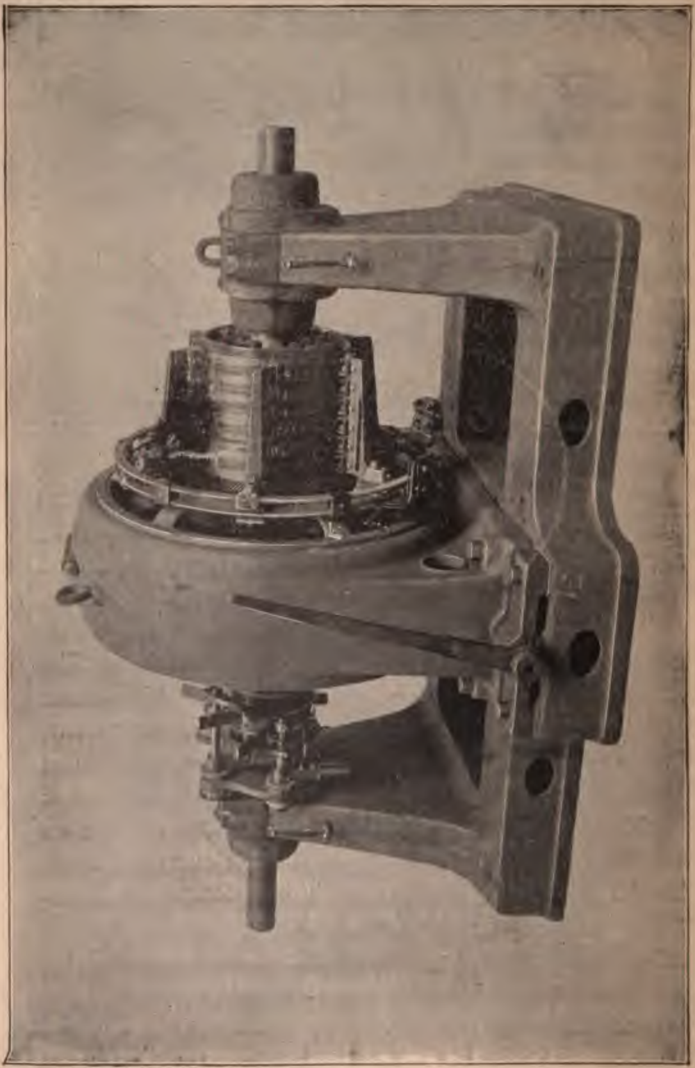

Fig. 62.

apart, by wires connected with the four collecting rings shown on the left end of the armature shaft. The current is received from a two-phase alternator by four brushes in contact with these rings, and after traversing the machine and being made direct by the commutator shown on the right, is transmitted by the commutator brushes through the external circuit. The rotation of the armature is produced by the current, as in the electric motor; hence the machine is appropriately called a *rotary transformer*, since it has the functions of self rotation and current transformation.

It should be stated here, that the construction of an electric motor is practically the same as that of a dynamo, so that a dynamo can be used as a motor, as in this case; the armature of a dynamo being rotated by an external force in opposition to the magnetism generated by its own current, while the armature of a motor is rotated in obedience to the magnetism generated by a current derived from an external source, as a dynamo or battery.

A small, two-phase, alternating current motor, not shown, is employed to start the transformer, and after proper speed has been attained, this motor is stopped by opening its circuit, and the transformer being put in operation by closing the main circuit, this rate of speed is maintained.

RELATIVE IMPORTANCE OF ALTERNATING CURRENT DYNAMOS.—The great improvements made in the construction of these dynamos within the last ten years has brought them into relatively greater importance than formerly, as compared with direct current dynamos. These improvements have overcome the defects which earlier restricted their use, without interference with the *primary advantage,* which they always possessed, of the elimination of the costly commutator, with its resistance, and the consequent greater E. M. F. which they are capable of generating, by which the electric current can be transmitted to relatively greater distances by smaller wires, thus effecting greater economy in line construction.

The construction of practical, alternating current motors, which were almost unknown ten years ago, has also contributed materially to this result; so that the alternating current can now be employed for the transmission of power, as well as for electric lighting, and applied without rotary transformation to the operation of machinery by these motors; while the construction of the rotary transformer renders its application to direct current motors, after transformation, also possible.

CHAPTER V.

ELECTRIC TERMS AND UNITS.

BEFORE entering upon an investigation of the principles which govern the construction of electric lamps, it is proper to define more fully various technical terms in common use in electric science, most of which have been frequently used in the preceding chapters, accompanied, as introduced, by brief definitions. This is the more important since their full import is not always clear, even to many who daily use them.

ELECTRIC POTENTIAL. — Potential is a convenient term used in various departments of physical science to represent the energy which a body may possess to accomplish work. A weight has gravity potential when it occupies such a position that it can accomplish work by its descent, a furnace, heat potential when it can accomplish work by its heat. So practically, without reference to mere theoretical distinctions, electric potential is the power which a body possesses to accomplish work by virtue of its electricity. But to accomplish work by gravity, heat, electricity, or other energy, there must always be a difference of potential, since in equality of potential the forces are equally balanced: a weight requires difference of level, heat, difference of temperature. So electricity can accomplish no work where the opposing electric conditions are equal; and the object of any electric generator, whether it be a battery, dynamo, or static machine, is not to create electric energy, — which is a physical impossibility, since, like gravity, it exists as a universal property of matter, — but to create a difference of electric potential.

Positive and negative are convenient relative terms to express differences of potential. A body is said to be positively electrified when by electric accumulation its potential rises above that of other bodies to which it may be related, either by contiguity of position or electric connection; and negatively when its electric potential is below that of the other bodies.

ELECTRO-MOTIVE FORCE. — Electro-motive force is the force or pressure which electric energy is capable of exerting by virtue of a difference of electric potential between the body in which it is accumulated and some other body. The force or pressure is exerted by the energy itself, the body in which it is accumulated or by which it is transmitted being merely a passive medium, and not, as in the case of steam and some other bodies, the active medium by which the energy is applied.

The term *pressure* has recently come into use in this connection, and perhaps expresses more clearly what takes place than any other term which can be found. It is the energy accumulated in steam, heated air, a descending weight, or a waterfall, which creates the pressure by which work is accomplished; and similarly, by its own peculiar process, electricity creates pressure, and accomplishes work.

The symbol for electro-motive force is E. M. F., and in mathematical formulæ E alone is generally used.

RESISTANCE. — Resistance is that which opposes electro-motive force; it may consist in counter electro-motive force, in useful work to be accomplished, in the imperfect conductivity of the conductor, or in an artificial obstruction placed in the circuit for a given purpose. It is important to distinguish carefully between internal resistance, which pertains to the generator or any electric instrument, and external resistance, which pertains to the general circuit. R is the symbol of resistance; and where both kinds are referred to in the same connection, r is used to indicate the internal, and R the external, resistance.

CURRENT. — Current is that electric condition in a conductor which results from electro-motive force modified by resistance. It pertains exclusively to what is understood as electric movement, and is used in the same sense when applied to this movement in a conductor, as when applied to the flow of water in a pipe; and in this sense also are used the terms current intensity, quantity, volume, strength, and resistance; and on this principle all the various kinds of electric apparatus pertaining to current are constructed, and current estimates and measurements made. In the present imperfect state of electric knowledge, this is doubtless the best that can be done; and yet it is doubtful whether there is any real resemblance between an electric current and a liquid current, or current of vapor or air. The generator creates E. M. F. at one end of the conductor, and a molecular movement is supposed to take place by which electric energy is instantly transmitted. Theoretically, this molecular movement is in the form of transverse vibrations; but as a matter of fact, its nature is unknown. It seems to be well established, however, that there is no transmission of any thing in the nature of a fluid or other matter, energy alone being transmitted, using matter as its medium.

Current movement is always from higher to lower potential, or, which is the same thing, from positive to negative. Hence, since E. M. F. depends on difference of potential, the strength of current passing through a circuit of no resistance from the positive to the negative side of the dynamo depends solely on the amount of this difference. But when the circuit includes lamps or other resistance, the strength of current depends on the E. M. F. divided by the resistance, according to Ohm's law, the case being analogous to that of water flowing through a pipe under pressure and resistance. Hence any variation, either of E. M. F. or resistance, changes the strength of the current; and where current constancy is required, as in electric lighting, it can be obtained by varying the E. M. F. in the same ratio as the resistance; and this, as we have seen, is done, in most cases, by shifting the position of the brushes on the commutator, in others by varying the number of armature or field-magnet coils in circuit. The strength of the current can also be varied by varying the resistance of a weaker opposing current, as has been shown.

To the ordinary mechanic or business man, accustomed to deal with material forces, and unversed in philosophic subtleties, the movement of electric energy in a conductor is often a profound mystery. He naturally associates energy and matter so intimately that he is unable to discriminate between them, or to conceive how energy can traverse a conductor unless it is a material substance of the nature of a fluid. And until recently philosophers found the same difficulty; hence the terms phlogiston and electric fluid, representing imaginary material substances, the supposed active principles of heat and electricity.

But while we do not know just how electric energy is transmitted, it is not difficult to conceive how it may be, since we have analogous instances; and the theory most generally adopted is that of vibration, which is the more probable since it is equally applicable to the kindred forms of energy, light, and heat. According to this theory, the molecules of the conductor are thrown into a state of intense vibration, transverse vibrations traversing it, and transmitting the energy in a manner analogous to that by which mechanical energy is transmitted through a series of suspended balls, or along the surface of a liquid.

The symbol of current is C; and the conductivity of a conductor, that is, its current capacity, without reference to the material of which it is composed, is inversely as its length, and directly as the area of its cross-section.

ELECTRIC INDUCTION. — By electric induction is meant the influence which a charged conductor exerts on another conductor in its vicinity, insulated from it. It may be considered under two divisions, — static induction and current induction; static induction pertaining to accumulators, as Leyden jars and condensers; and current induction pertaining to the mutual influence of currents.

If an accumulator is charged positively, it produces a corresponding negative charge on all bodies in its immediate vicinity, electricity equal to that of the positive charge being repelled from them: if negatively charged, a correspondingly equal positive charge is attracted, and accumulated on them. In either case there is no electric transfer of such a nature as to reduce the original charge: the accumulator, if positively charged, loses no electricity; and, if negatively charged, it gains none. This is proved by the fact, that, where surrounding objects are subsequently removed beyond the influence of the charged body, no permanent effects remain on them unless special means are used to render such effects permanent. This may be demonstrated by placing a gold leaf electroscope in the vicinity of the charged body, when the leaves will indicate the charge by their divergence; but on being removed, they converge again. To make this effect permanent, let the plate of the electroscope, while under the influence of the charge, be touched by a conductor connected with the earth; a transfer of electricity will now take place, either to or from the earth, according as the charge is positive or negative, establishing equilibrium between the electroscope and charged body, as indicated by the convergence of the leaves, thus proving the fact of attraction or repulsion of electricity, as stated above; then, on the removal of the electroscope from the influence of the charged body, difference of potential asserts itself, and the leaves diverge. Now, since the electroscope is simply one of the surrounding bodies under inductive influence, so constructed as to indicate it, we must infer that all other bodies similarly placed are similarly influenced.

Induction can take place only through an insulating medium, — as air, glass, or an insulating envelope, — which is termed the dielectric. Its nature is not fully understood; but since there is no actual transfer of electricity, and since energy can act only through matter as its medium, it is evident that the dielectric, in some unknown manner, becomes the medium of this subtile influence. The definition, "direct action at a distance," formerly used by some leading electricians, is too vague, and has been abandoned since the nature of electric action has come to be better understood.

Current induction is of the same nature as static, modified by the properties peculiar to currents. That which we call a continuous current is in reality a succession of impulses or infinitesimal currents, as has been already explained; and the conductor throughout its entire length, whether it be an Atlantic cable or a foot of wire, has practically, at each successive instant, a static charge modified by the difference of potential between its extremities, by virtue of which the transfer of energy takes place; consequently this charged conductor, like other charged conductors, exerts inductive influence on adjacent conductors.

When a current flows through a conductor, it is found that the effect of induction is to produce an opposite current in any adjacent parallel conductor. The nature of this action may be represented by the following diagram:

$$
\begin{array}{l}
(a) + 10 + + + + + + + + + 1 \\
(b) - \;2 - - - - - - - - - \tfrac{1}{5}
\end{array}
$$

Let *a* represent a conductor in which a current is flowing from left to right by virtue of the difference of potential represented by + 10 at the left and + 1 at the right; and let *b* represent an adjacent parallel conductor. Since inductive influence radiates from the charged body equally in all directions, only a small fraction of the lines of electric force radiating from *a* are intercepted by *b;* but, for convenience, we may represent this fraction by $-\frac{1}{5}$ at the right, and -2 at the left. Now, since, as has been shown, the positive produces by induction an equal corresponding negative, and *vice versa*, the positive potential in *a*, represented by + 10, produces, under the conditions named, a negative potential in *b*, represented at the adjacent point at the left by − 2, while at the right + 1 in *a* produces $-\frac{1}{5}$ in *b;* and since electric movement is always from higher to lower potential, the current in *b* must flow from right to left, opposite to that in *a*.

Hence, when currents in two or more adjacent parallel conductors flow in the same direction, the effect of their mutual induction is to produce in each a counter-current, which reduces the volume of the primary current; the effective current by which useful work is accomplished being then represented by the difference between the two. As in the illustration, if the primary current were represented by 10, and the induced opposing current by 2, the effective current would be represented by 8.

But if the primary currents flow in opposite directions, the effect of induction is reversed, and the volume of effective current in each conductor increased, as can easily be seen by the following diagram:

(*c*) + 10 + + + + + + + + + 1
(*d*) + 1 + + + + + + + + + 10

in which the current in *c* flows from left to right, and in *d* from right to left. The positive potential 10, at the left of *c*, induces at the same end of *d* a much stronger negative than the potential 1, of *d*, can induce in *c:* consequently the difference of potential between the opposite extremities of *d* must be greater than if *c* were removed, and hence its E. M. F. and resulting volume of current must be greater. And the same effect in *c* must follow from the difference of potential at the right between the 10 of *d* and the 1 of *c*.

The effect of induction in increasing current strength at the expense of E. M. F., or E. M. F. at the expense of current strength, has already been sufficiently explained in connection with the subject of converters, treated of in Chapter III., so that further reference to it is unnecessary.

MAGNETIC INDUCTION. — Magnetic induction, while strongly resembling electric induction, must be carefully distinguished from it: their effects are reciprocal, not identical. Practically, magnetic induction is found only in connection with iron and steel, though some other metals are slightly magnetic; and, as we have seen, the construction and operation of the dynamo is dependent on the reciprocal action of magnetic and electric induction, the electric current being generated by the magnetic induction of the iron cores of the field-magnets and armature, and reciprocally, magnetism being generated by the electric induction of the current in the coils. The directions of the magnetic and electric currents produced by this reciprocal induction are always at right angles to each other; the magnet and the coil or line conveying the electric current, if free to move, always assuming this relative position with respect to each other.

The induced current, as has been repeatedly stated, is a momentary transient impulse which occurs at the instant an electric circuit is either opened or closed; its direction on the opening of the circuit being the reverse of that on the closing: and the continuous current of the dynamo, whether constant or alternating, is composed of a series of these impulses, induced, not by the opening or closing of the circuit, but by a reversal of the position of the coils of the armature by their rotation, and consequently of the relative direction of magnetic induction.

In the case of induction coils, the primary circuit is opened and closed successively, with great rapidity, by a circuit-breaker, and the series of impulses constituting the current, in the secondary circuit induced thereby. It is found that the current induced by the opening of a circuit is far more powerful than that induced by the closing. This is due to the transient current termed *extra*, resulting from self-induction between the adjacent windings of the coil; which is inverse on closing the circuit, neutralizing the original current to the extent of its strength, but direct on opening, adding its strength to that of the original current. The greater strength of the latter current, in the primary coil, is shown by the spark which appears at the break, on opening the circuit, but is never seen on closing it. In the case of accidents requiring the sudden stoppage of the dynamo, it is of the highest importance that the greater energy of this current should be guarded against by suitable construction, such as a short-circuiting switch or other similar device.

In concluding these remarks on the nature and general principles of induction, which have been thus briefly indicated, it should be stated that when we consider that induction permeates every portion of every electric instrument, its force radiating from every charged conductor, the great importance of a thorough comprehension of its principles and their application becomes evident. It must be recognized, not as an obstacle to be overcome, — though it often stands in the way of desirable ends in construction,—but as an important factor in the accomplishment of electric work, without which the construction and operation of the existing forms of electric apparatus would be an impossibility; and it is coming to be understood that it is better always to recognize it as a friend than as a foe.

CONDUCTIVITY AND INSULATION.—Conductivity is that quality of a body which facilitates electric transmission: insulation is its opposite, and obstructs electric transmission. The distinction between the two when applied to bodies is one of degree, the one being the reciprocal of the other. There is no well-defined boundary showing where conductivity ceases, and insulation begins: every conductor is an insulator so far as it tends to resist electric transmission, and every insulator is a conductor so far as it tends to facilitate such transmission. Where conductivity is found to predominate, as in the metals, the term conductor is applied; and where insulation predominates, as in glass and vulcanite, the term insulator is applied. The terms high and low are applied to conductors to designate different degrees of conductivity, or, conversely, different degrees of resistance; and to insulators to designate different degrees of insulation. Silver and copper, for instance, are metals of the highest conductivity, and conversely of the lowest resistance: bismuth and german-silver have high resistance, and consequently low conductivity. Glass and vulcanite have high insulation, and correspondingly low conductivity,—so low that the term conductor is never applied to them; nor is the term insulator ever applied to silver or copper. Hence a conductor is any substance of such low resistance that it can be used practically for the transmission of electricity, and a non-conductor or insulator is any substance of such high resistance that it can be used practically to prevent such transmission.

Difference of molecular constitution is the most reasonable explanation that can be given of these different phenomena; but just how such difference produces these varied results, is unknown. But we may reasonably attribute them to difference in molecular arrangement. If we compare the molecules to an infinite number of infinitesimal tubes, and electricity to a fluid passing through them, it is evident that were these tubes placed end to end, in series, the flow would be facilitated; but if disposed traversely, or in a heterogeneous manner, the flow would be obstructed. Similarly we may suppose the relative arrangement of the molecules in one substance to be such as to facilitate, and in another to obstruct, electric transmission. If, as seems highly probable, electricity is a mode of molecular motion by which energy manifests itself, the above explanation seems entirely reasonable; difference of arrangement or difference of shape in the molecules, or both combined, producing differences in the mode of interaction.

QUANTITY AND INTENSITY. — The comparatively imperfect state of electric knowledge has led to a misuse of the terms quantity, intensity, and strength as applied to current, each writer using them according to his own mental conception of the facts, or carelessly following the general custom. Whatever current may be, its quantity, as observation proves, must be regarded in the same light as that of any physical quantity; so that whether we consider it as energy flowing through the conductor as its passive medium, or as producing molecular motion in the conductor itself, as already explained, it has a certain volume in the same sense as a fluid — water or gas — flowing through a pipe; and this volume, as in the case of fluids, is dependent on the resistance encountered and the pressure urging it forward, known as E. M. F. With a given conductivity and E. M. F., any increase of cross-section by the substitution of a larger conductor, or a greater number of conductors, produces an increase in the quantity or volume of the current, and a corresponding decrease of intensity at each point in cross-section, by distributing the original intensity over a larger area; and a reversal of these conditions produces the opposite effect. Conversely with a given conductivity and cross-section in the conductor, any variation in the E. M. F. produces a corresponding variation of intensity.

Electric intensity has been regarded as analogous to momentum; but since momentum is the product of mass and velocity, and since mass is not a factor in electric intensity, the analogy fails. But if we regard electric intensity as the result of molecular movement in the conductor, produced by E. M. F., we shall probably come nearer the exact truth.

It has also been assumed that the constancy of an electric current is maintained by an increase of velocity in the inverse ratio of the reduction of cross-section in the conductor, in a manner analogous to that in which constancy of quantity is maintained in a fluid current by an increase of velocity in the inverse ratio of reduction in size of pipe, the same quantity passing through the smaller pipe in the same time as through the larger, by an increase of velocity; but since the velocity of an electric current has never been estimated except by the remotest approximation, the analogy fails, as in the former instance. But if we regard varied quantity and intensity of molecular vibration, produced by a variation in the amplitude or the length of the waves, by which electric energy is supposed to be transmitted, as the true explanation, our conceptions of these phenomena become much clearer.

ELECTRIC UNITS. — In order to render possible the calculations required in the various departments of electric work, and especially in electric engineering, it becomes necessary to have certain units of measurement especially adapted to the peculiar electric conditions found in electro-motive force, resistance, and current. It is also necessary that these units should be established by some authoritative source, universally recognized and acknowledged. The International Electric Congress, composed of leading electricians of various nationalities, which met at Paris in 1881 and 1884, was such a body; and the electric units it adopted after careful deliberation have been accepted as authoritative. Most of these units were previously in use; and the work of the Congress consisted chiefly in giving them definite value, referable to fixed standards, and eliminating various errors.

The work accomplished by electric energy furnishes the means for absolute measurement, and the C. G. S. mechanical unit is taken as the basis for the electric unit. The initial letters, C. G. S., are the symbols of the three factors, space, mass, and time; C. standing for centimeter, G. for gramme, and S. for second. Hence this C. G. S. unit represents the work accomplished by the movement of a mass equal to one gramme through a space equal to one centimeter in one second, known as the erg.

The term "legal" is applied to the units adopted by the Paris congress to show that they are properly authorized, and to distinguish them from similar units previously in use. Hence, the following are the practical legal electric units based on the C. G. S. system:—

THE VOLT.—The unit of electro-motive force is the volt, named after Volta, the original inventor of the primary battery. The E. M. F. of a battery cell nearly equal to that of the Daniell, was originally adopted as the standard unit; but, as the E. M. F. of a cell represents a variable quantity, a definite value was given this unit by the adoption of 100,000,000 C. G. S. units as the standard, which consequently represent the amount of electric energy, which, if converted without loss, would equal this amount of mechanical force; but, as large numbers are inconvenient to write, the equivalent expression, 10^8, has been adopted, and the same method of notation followed in regard to the other units. Hence, the legal volt equals 10^8 C. G. S. units. In approximate calculations, where strict accuracy is not required, the E. M. F. of the ordinary Daniell cell is still taken to represent the volt, its energy being about 1.05 volts.

THE OHM.—The unit of resistance is the ohm, named after Ohm, who discovered and formulated the law of electric resistance. The resistance of a given number of feet of wire—copper, iron, or german-silver—of a given gauge was the original standard; but the Paris congress, acting upon the suggestion of Sir William Siemens, adopted as the standard a column of pure mercury, 106 centimeters in length, and 1 square millimeter in cross-section, at the temperature of 0° C. Its resistance is represented, to within a small fraction, by 10^9 C. G. S. units; the actual resistance represented by this expression being equal to that of a column of mercury, of the same section and temperature, 106.21 centimeters in length; but, to avoid the fraction, the standard was fixed as above. The legal ohm, then, equals 10^9 C. G. S. units of resistance.

The Ampere. — The unit of current strength or volume, as has been explained, is the ampere, named after Ampere, who discovered and formulated the laws of electric currents. It is derived from the two preceding units in accordance with Ohm's law; current being equal to E. M. F. divided by resistance $\left(C = \frac{E}{R}\right)$ hence since $\frac{10^8}{10^9} = 10^{-1} = \frac{1}{10}$, the legal ampere equals 10^{-1} C. G. S. units of current strength. The element of time is not included in this unit. It refers exclusively **to the strength of the current,** as represented by its cross-section.

The Ampere-Hour. — The ampere-hour is a unit derived from the last, in which the element of time is included. It represents a current of one ampere flowing through a conductor for one hour, or its equivalent in a greater or less current for a greater or less time, as two amperes for half an hour, or half an ampere for two hours. It is of recent origin, but is sanctioned by general use, and is often convenient in electric calculations.

The Coulomb. — The unit of current quantity, considered with reference to time, is the coulomb, named after Coulomb, to whom is due the first attempt at accuracy in electric science. It is derived from the ampere, and represents the quantity of electricity which flows in a current of one ampere in one second. Hence, any variation, either in the time or strength of current, produces a corresponding variation in the quantity represented in coulombs; a ten-ampere current flowing for one second, or a one-ampere current flowing for ten seconds, represents ten coulombs; and, since there are 3,600 seconds in an hour, 3,600 coulombs equal one ampere-hour. The coulomb equals 10^{-1} C. G. S. units of current quantity.

THE FARAD. — The electric unit of capacity is the farad, named after Faraday. It represents the storage of one coulomb of electricity in a condenser; and, when such storage raises the potential to one volt, the condenser is said to be of one farad capacity. The farad equals 10^{-9} C. G. S. units of capacity.

THE MICROFARAD. — The farad being inconveniently large for practical use in the construction of condensers, the microfarad, representing one-millionth of a farad, has been adopted in its stead. Hence the microfarad equals 10^{-15} C. G. S. units of capacity.

THE WATT. — The unit of electric power is the watt, named after Watt the inventor of the steam-engine. It is derived from electro-motive force and current combined, neither of which, taken alone, is an exact representative of electric power, since current is derived from resistance and E. M. F., either of which may vary, producing a variation of current; or one may vary directly as the other, producing a constancy of current; hence, to obtain an accurate expression for electric power, or rate of work, the E. M. F. is multiplied into the current, — that is, the volt into the ampere. A watt then equals one volt multiplied into one ampere, which equals 10^7 C. G. S. units of power ($10^8 \times 10^{-1} = 10^7$). The term volt-ampere is synonymous with watt.

THE ELECTRIC HORSE-POWER. — The electric horse-power, which is the equivalent of the mechanical horse-power, is represented by 746 watts, equal to $746 \times 10^7 = 7,460,000,000$ C. G. S. units of power.

THE JOULE. — The electric unit of heat is the joule, named after Joule who discovered and formulated the law by which the electric current develops heat. It represents the heat developed in a conductor by one watt in one second; which equals the square of the current's strength multiplied by the resistance and time, represented by $H = C^2Rt$; H representing heat and t time; which, reduced to the C. G. S. units represented by $(1 \text{ amp.})^2 \times 1 \text{ ohm} \times 1 \text{ sec.}$, gives $H = (\frac{1}{10})^2 \times 10^9 \times 1 = 10,000,000$.

Joule found that the heat required to raise the temperature of 1 gramme of water 1° C. is equivalent in work to 42,000,000 C. G. S. units, which is known as *Joule's equivalent.*

As the ratio of the joule to this is $\frac{10,000,000}{42,000,000} = 0.238$, this fraction represents the relative amount of heat which the joule can develop. Hence the formula, C^2Rt, must be multiplied by 0.238 to reduce the C. G. S. units of work represented by the joule to heat units, as represented by Joule's equivalent, which gives $H = C^2Rt \times 0.238$.

THE HENRY.—The unit of inductance (or self-induction) is the henry, named after Henry, the first observer of this principle. It represents the induction in an electric circuit, when the induced E. M. F. is 1 volt, and the inducing current varies at the rate of 1 ampere per second. Its value is 10^9 C. G. S. units.

CHAPTER VI.

ELECTRIC MEASUREMENT.

INSTRUMENTS for electric measurement are constructed either on the principle of electric attraction and repulsion, on the relations between electricity and magnetism and between resistance and E. M. F., on the heat developed by the electric current, or on the amount of metal deposited or gas generated by electrolysis. Those constructed on the principle discovered by Oersted, that the magnetic needle tends to assume a position at right angles to the direction of the electric current, are known as galvanometers, and are chiefly used to measure battery currents; while those constructed on the principles of electrolysis are known as voltameters, and are used to measure the electro-motive force of batteries. But the powerful currents and great E. M. F. developed by the dynamo, has led to the invention of instruments of special construction, known chiefly as voltmeters and ammeters; voltmeters designating those which measure electro-motive force, the results being given in volts; and ammeters those which measure current strength, the results being given in amperes. Ammeters are also called current meters and ampere meters. There are also instruments of special construction designated as electro-dynamometers, coulomb-meters and ohm-meters.

It is evident, that since current is derived from E. M. F. and resistance, if two of these three quantities are known, the third can easily be found by one of the following formulæ,

$$\left(C = \frac{E}{R}\right), (E = CR), \left(R = \frac{E}{C}\right),$$

Hence C and E being ascertained by measurement, R can be ascertained by calculation.

There are also instruments known as potential indicators, which do not measure E. M. F., but are arranged to indicate deviations above or below a certain normal E. M. F., and are placed permanently in the circuit, like the steam-gauge on the boiler, as a guide to the engineer or attendant; while measuring instruments are used chiefly in making tests.

THE POTENTIAL INDICATOR. — Fig. 63 shows a potential indicator used by the United States Electric Lighting Company. It is constructed on the principle of the electric motor, or reversed dynamo, current producing motion, instead of motion producing current. Two horse-shoe magnets with consequent poles, placed horizontally, as shown, form the magnetic field in which is placed the armature, shown at the center; the armature core is a cylinder of soft iron, laminated, placed vertically in a fixed position. A helix of fine copper wire, wound on a copper ring and placed vertically also, surrounds the core, but is insulated from it, an air space intervening between them. This helix is suspended by a fine phosphor-bronze wire attached below to the base of the instrument, and above to a screw with a milled head, connected to a short arm projecting from a vertical support. A long pointer projects towards the front, and is bent downwards at right angles over a circular scale, which indicates, to the right, five volts above, and to the left, five volts below, a certain normal E. M. F. indicated by zero; each of the numbers, 10, 20, 30, 40, 50, indicating about a volt, and each volt space being subdivided into tenths, as shown. The instrument is inclosed in a glass case, and supported on leveling screws. It has a very high resistance, and is connected directly between the positive and negative leads *at the point* where the electric pressure should be

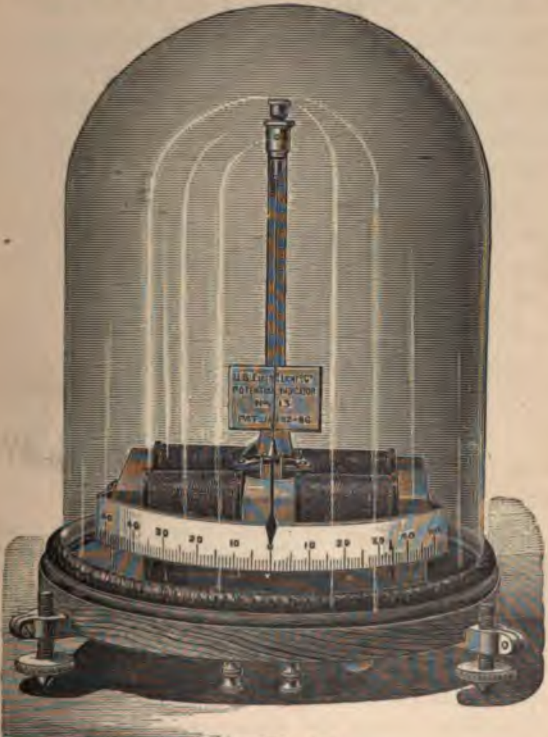

Fig. 63.

kept constant. The resistance being very high, only a very small fraction of the current will pass through it. The armature helix is connected in series with the field-magnet coils, as in the series dynamo; and the current causes it to rotate round its core so as to move the pointer over the scale from left to right in opposition to the torsion of the wire by which it is suspended, current producing motion as stated above. The torsion is so adjusted that the required E. M. F. brings the pointer to zero; hence its movement to the right of zero shows that the E. M. F. is too high, or, to the left, that it is too low. By an increase or decrease of torsion, the normal E. M. F. can be varied within certain limits.

VOLTMETERS AND AMMETERS.—The difference between these two instruments consists chiefly in the respective resistance of each, and its relative position in use; the voltmeter having high resistance and being placed in a derived circuit between the points whose difference of potential is to be measured, while the ammeter has low resistance and is placed directly in the main circuit at any point where current strength is to be measured.

THE WESTON VOLTMETER.—This instrument, shown by Fig. 64, incloses within its case a powerful steel horseshoe magnet, the poles of which project into the narrow space in front and are attached to two soft-iron pole-pieces, as shown in Fig. 65. These inclose a circular space, within which is mounted a soft-iron armature core, maintained in a fixed central position by attachment to a brass yoke which connects the pole-pieces; part of this yoke, with its right-hand connection and a central projection for attachment of the core, being shown.

A light copper frame, $\frac{3}{8}$ of an inch wide, and wound with a coil of fine, insulated, copper wire, surrounds the core, and has a limited rotary motion, on jewelled bearings, in the narrow space between the core and pole-pieces, which is just wide enough to allow rotation without contact.

The terminals of the coil are connected above and below with two flat springs, oppositely coiled, and so attached to the copper frame and adjoining parts as to maintain the coil in a fixed position, when the springs are not under tension, and bring a light aluminium pointer, attached to the frame, to zero of the scale on the left.

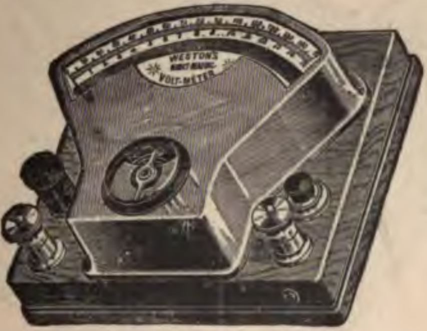

Fig. 64.

These springs are made of a special, non-magnetic alloy, and are placed in opposition to neutralize the effects of expansion and contraction under variations of temperature.

A resistance coil, mounted within the case, makes electric connection, by one of its terminals, with one of the springs, while the other terminal is connected with the front binding-post on the left. Another connection with the rear binding-post on the same side taps this coil at a point nearer the spring, so as to include a much lower resistance. The other spring is connected with the binding-post on the right, back of which is a contact key and a calibrating coil. This part of the circuit can be closed permanently, after calibration, by depressing the key and giving it a quarter-turn.

When connections with an electric source are made b

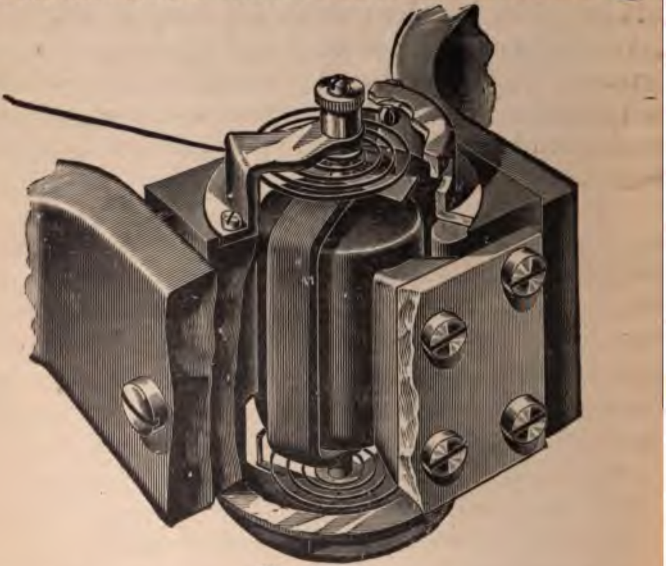

Fig. 65.

the right binding-post and either of the two on the left, the current enters and leaves the copper coil through the springs, its direction and the winding being such as to produce deflection from left to right; the coil tending to rotate into a position at right angles to the lines of magnetic force, in opposition to the tension of the springs. And the instrument being calibrated in accordance with the resistance of its coils, the deflection of the pointer will indicate the difference of potential in volts; since with a given resistance the E. M. F., or potential difference, varies directly as the current strength.

The entire resistance is to that of the sectional part in the ratio of 20 to 1; the divisions of the scale being in volts for the outer reading, corresponding to the high resistance, and the same in twentieths of a volt for the inner reading, corresponding to the low resistance, as shown. Hence the E. M. F. which will produce a deflection of one division, when connection is made with the front binding-post on the left, will produce a deflection of twenty divisions when connection is made with the rear binding-post.

The high-resistance circuit is used for apparatus generating strong currents, as dynamos, and the low-resistance circuit for apparatus generating weaker currents, as primary batteries, on account of its greater sensitiveness: and as a dynamo current would be likely to injure or destroy the copper coil, if admitted through the low resistance, the rear post is protected from accidental contacts by an outer covering of hard rubber. In some of the instruments all the posts are similarly protected; the rubber also preserving the contacts from oxidation. The scale readings also vary in different instruments.

The deflection of a current-bearing coil in a magnetic field of special strength gives the instrument great superiority over instruments depending on the deflection of a steel or soft-iron needle; the magnetic action being stronger, and its relation to the current more direct. The constancy of the instrument is dependent solely on the constancy of the magnet, the springs, and the internal resistance.

THE WESTON AMMETER.—The construction of the Weston ammeter is similar to that of the voltmeter, but simpler; the chief differences being that the copper coil is of coarser wire, having much lower resistance, and the resistance coil is not required: hence there are only two binding-posts and a single circuit, directly through the copper coil and springs.

The scales for different instruments range from 5 amperes, with divisions of $\frac{1}{20}$ of an ampere, to 100 amperes, with divisions of 1 ampere, according to the relative resistance of the coils.

THE WESTON MILLIAMMETER.—This instrument has the same construction as the ammeter, but lower resistance. Instruments of two different resistances, with scales of corresponding difference, are constructed; one of 300 milliamperes, with scale divisions of 2 milliamperes each; and the other of 600 milliamperes, with scale divisions of 4 milliamperes each.

A milliampere being $\frac{1}{1000}$ of an ampere, it is evident that these instruments are capable of measuring very low currents, especially as the scale divisions are readable to fifths; so that the smaller instrument can indicate a current of $\frac{1}{5}$ of 2 milliamperes, $= \frac{1}{2500}$ of an ampere.

THE WIRT VOLTMETER.—This instrument, illustrated by Fig. 66, is constructed on the principle of ascertaining the E. M. F. to be measured by comparison with a known E. M. F.; each being proportional to a resistance having similar conditions through which the measurement is made.

The case incloses two Clark cells, each having a constant E. M. F. of 1.43 volts, the connections being so arranged that either can be employed alone, or the two joined in series so as to obtain an E. M. F. of 2.86 volts. Under the glass cover is shown a small galvanometer, with magnetic needle, light aluminium pointer, and terminal wires connected with the coil; also a small scale, not shown, under the pointer, having a limited range, in opposite directions, from 0 at the centre.

Extending round the case inside is a coil of german-silver wire, having a resistance of about 2500 ohms, one terminal of which is attached to one of the binding-posts shown on the right, marked +, while a sliding contact, which can be moved to any required point on this coil, is connected with the other binding-post, marked — ; and this contact is attached to the rim of the hard-rubber cap, shown above, which can be rotated on the interior part of the cap, on which is shown a scale graduated in volts, from 1½ to 120. By rotating this rim, a short in-

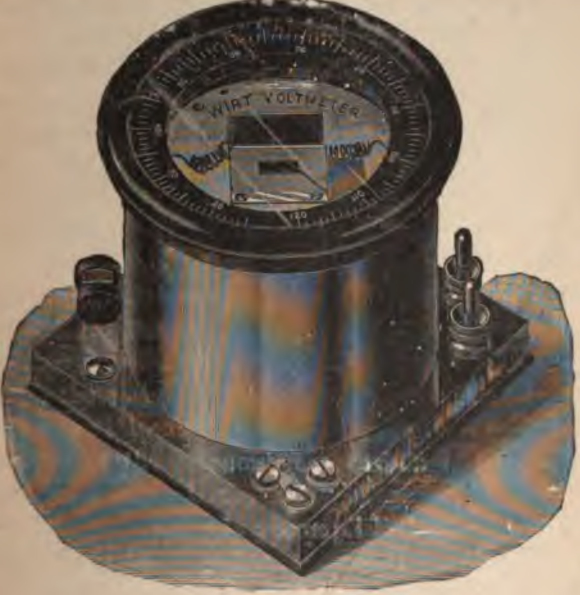

Fig. 66.

dex, attached to it, is moved to any required point on the scale, the sliding contact being moved simultaneously, so as to include any resistance required between the terminals of the binding-posts.

The galvanometer circuit also includes a certain portion of this coil, having a known resistance calibrated with reference to the known E. M. F. of the battery cells, which are also included in this part of the circuit. A contact key, shown on the left, closes this circuit through the galvanometer, producing deflection of the needle and attached pointer.

If connection with a generator whose E. M. F. is to be measured be made through the binding-posts, so that the current shall oppose the meter's battery current, the needle will be deflected, when the contact key is closed, so long as the generator current is stronger or weaker than that of the battery.

Let the instrument be so placed that the earth's magnetism shall bring the galvanometer pointer to 0 on the small scale; and let the rim be turned so as to bring the attached index near the probable E. M. F. on the large scale; then, deflection being produced by closing the contact key, let the rim be turned so as to include sufficient resistance to equalize the opposing currents and bring the galvanometer pointer back to 0; the index will then show the E. M. F. of the generator in volts on the large scale. For since, with a given current, E. M. F. varies directly as resistance, if the E. M. F. of the battery be represented by E and that of the generator by E', the resistance of the battery circuit by R and that of the generator circuit by R', then $R : R' :: E : E'$. That is, the resistance of the battery circuit is to the resistance of the generator circuit as the E. M. F. of the battery is to the E. M. F. of the generator, and the calibration gives this E. M. F. in volts.

A switch is shown in front by which connection can be made with either of two separate circuits, the right-hand contact, marked $\frac{1}{10}$ to indicate the relative measurement of E. M. F., connecting with one having ten times the resistance of that connected with the left-hand contact. At the opposite corner, in the rear, three battery connections are arranged, the right and left ones, marked *A* and *B*, being each through a separate cell, and the central one, marked 2, through the two cells in series; a plug closing whichever connection is to be used. When the switch is on contact 1. as shown, and the plug in *A* or *B*, the scale readings require no correction, and should be the same with the plug in either hole, each cell being a check on the accuracy of the other. But when the plug is in hole 2, the cells being in series, the reading must be multiplied by 2, since the battery E. M. F. is doubled; for $R : R' :: 2E : 2E'$.

But when a generator of low E. M. F. is to be tested, the switch is connected with the contact marked $\frac{1}{10}$, which includes, in the battery circuit, a resistance of ten times that included by contact 1; hence, since the battery current with this resistance is only $\frac{1}{10}$ of what it was with the former resistance, $\frac{1}{10}$ the E. M. F. will develop an opposing current of equal strength, giving the same reading, which must be divided by 10 to give the correct E. M. F.; for $10R : R' :: 10E : E'$.

Each cell is $1\frac{5}{8}$ inches high and $\frac{5}{8}$ of an inch in diameter, constructed with an inverted glass cup, inclosed in a brass case and hermetically sealed with soft rubber melted into the bottom.

The electrodes are zinc and mercury, and the fluid sulphate of zinc and sulphate of mercury, formed into a paste in which the electrodes are inclosed; connection with the mercury being made by an insulated platinum strip which represents the positive pole.

This cell is selected on account of the remarkable constancy of its E. M. F., and the instrument is calibrated for a cell temperature of 21° C., requiring a correction in the reading of .000367 per degree of variation above or below 21° C., which must be made by subtraction for the higher temperature. and by addition for the lower.

The cells are easily removed and replaced, when necessary, without disturbing the connections, and being small, hermetically sealed, and amply protected, do not interfere in the least with the handling of the instrument, and can be cheaply replaced when exhausted.

AYRTON AND PERRY'S SPRING VOLTMETERS AND AMMETERS.—The unreliability of electric measuring instruments constructed with permanent magnets, liable to magnetic loss, or to variation of magnetism from the influence of powerful currents, and consequently requiring frequent recalibration, has led to improved methods of construction, of which the spring voltmeters and ammeters of Ayrton and Perry are a result. Fig. 67 represents the ammeter, the voltmeter being of similar construction; the principle being simply the torsion of a spring by electromagnetic attraction.

The current passes through a long, narrow vertical coil, of high resistance in the voltmeter and low resistance in the ammeter, within which is suspended a light soft-iron tube, which incloses a long spiral spring of phosphor-bronze ribbon. This spring supports the tube, being attached at bottom to a brass cap in which the tube terminates, and above to a milled head which rests on the glass cover and is connected with the spring by a vertical pin which passes through the glass; a similar pin projects downward from the bottom of the brass cap and passes through a hole in a support below, in which it has a free vertical movement; so that the two pins hold the spring and tube in a vertical position; and the tube being shorter than the coil, its centre on a vertical line is above that of the coil. To the top of the tube is attached a light pointer which rotates over a scale graduated either in volts or amperes according to the design of the instrument.

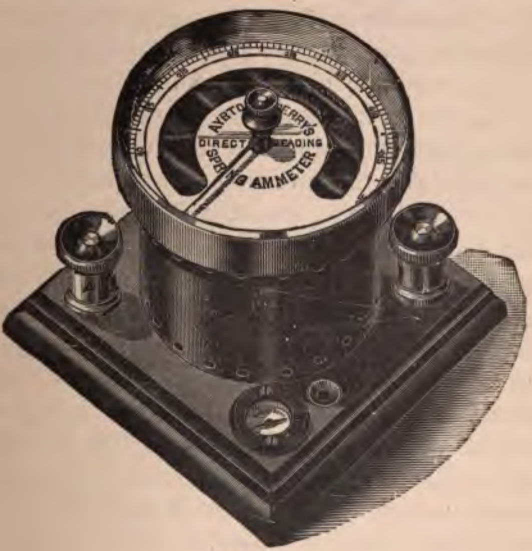

Fig. 67.

When no current is passing the pointer indicates zero on the left of the scale, but when the current passes the tube is pulled down by magnetic attraction, in opposition to the torsion of the spring, to a distance proportional to the current's strength; giving it a rotary motion by which the pointer is deflected, which indicates by direct readings the E. M. F. in the voltmeter, and the current strength in the ammeter, according to the respective resistance of each instrument, and its position in the electric circuit.

The tube can be turned by the milled head so as to bring the pointer to the required position in calibrating; and a reflected image of the pointer, in a mirror placed under it, enables the observer to determine accurately its position on the scale.

A little magnetic needle, shown at the front corner of the base, indicates the direction of the current; but as such a needle is liable to have its poles reversed by powerful currents, a bar magnet is preferred for this purpose. Since the deflection of the pointer depends on the magnetic attraction of the tube downwards, it must evidently be always in the same direction, and hence independent of the direction of the current; so that while this direction may be ascertained as above it is not essential to the use of the instrument that it should be known.

A light movable auxiliary coil surrounds the main coil and is connected with it in parallel; this can be moved up or down in calibrating till a position is reached in which its inductive influence on the main coil is best adapted to the construction, where it is made stationary.

The case is ventilated, as shown, to prevent the accumulation of heat generated by the current, which would expand the spring and produce inaccuracy. The usual binding-posts connected with the terminals of the coil are shown at the right and left, the left post being marked *A* to distinguish them in use.

The voltmeters are usually constructed to measure E. M. F. ranging from 15 volts to 1000; the ammeters, to measure current strength ranging from $\frac{1}{10}$ of an ampere to 600 amperes.

GRAVITY AMMETERS.—While springs have greater constancy than permanent magnets in the construction of electric measuring instruments, their constancy is liable to vary, or be impaired, from well-known causes, as heating, age, and use, imperfect material, or oxidation; but the force of gravity, being always known and constant, may be utilized in such construction to produce instruments of great constancy. On this principle the United States Electric Lighting Company constructed the ammeter shown in Fig. 68.

Two pairs of electromagnets, wound with coils of low resistance, and having laminated soft-iron cores, are placed as shown; each pair having its coils wound on the same core, producing consequent poles, but magnetically insulated from the other pair.

At the center, between these magnets, is mounted a soft-iron armature, lightly poised on a horizontal axis, the end of which is seen through the circular opening, and having a vertical rotary movement parallel to the magnets' plane. This armature is about 2 inches long, $1\frac{1}{2}$ inches wide at each end, $\frac{5}{8}$ of an inch at the center, and $\frac{1}{8}$ of an inch thick; its sides concave, and its ends convex, and slotted to correct the effects of residual magnetism. A pointer, attached to its axis, indicates the readings on a scale above, as shown.

When no current is passing, the armature is maintained in a fixed position by one or more little weights attached to its lower left-hand corner, its longer axis being on a diagonal line between the lower left and upper right-hand corner of the instrument, and the

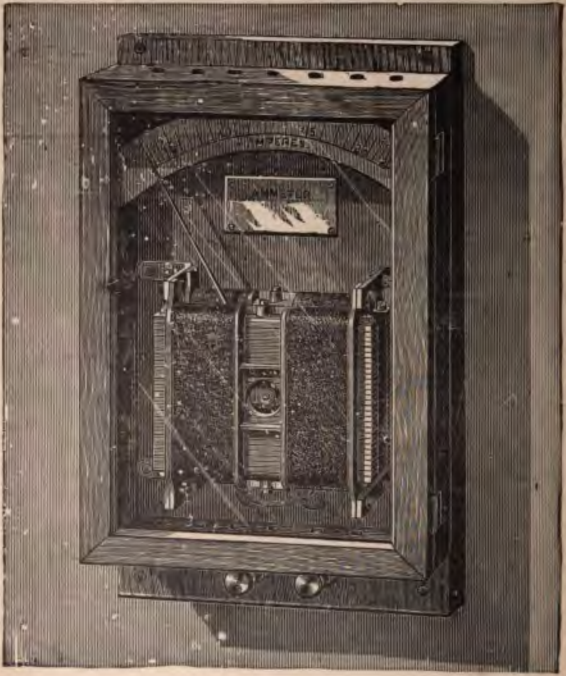

Fig. 68.

pointer at zero on the left of the scale. But when the current passes through the coils in either direction, the armature rotates in obedience to the electromagnetic force, its longer axis tending to assume a horizontal position, and the pointer is deflected from left to right in proportion to the current strength, which is indicated by direct reading in amperes.

By the removal or addition of one or more of the little weights, the sensitiveness of the instrument may be varied in calibrating, as required for different ranges of current strength. The terminals of the coils are shown at the base, and holes for ventilation at the top of the case.

Instruments constructed on this principle have not been employed to any great extent as voltmeters, not being sufficiently sensitive for the light currents required.

Since the weight, as it rises, recedes from the vertical line which passes through its axis of rotation, the force opposing rotation increases in the direct ratio of the increase of leverage thus produced. Hence, as equal divisions of the scale would represent unequal increments of current strength, they should be made in the inverse ratio of this increase of leverage.

But as it is difficult to mark off such short spaces with the requisite accuracy, a gravity ammeter has been constructed by the Western Electric Company, with a vertical electromagnet having a pole-piece so curved that the rotating armature, as it rises, constantly approaches it, the magnetic attraction increasing in the same ratio as the leverage, so that equal divisions of the scale represent equal increments of current strength.

The Cardew Voltmeter.—The instruments thus far described are designed to be used with direct currents, and are liable to errors arising from self-induction in addition to those from the other causes mentioned. But since, according to a well-known law, the heat developed in an electric conductor is in direct proportion to the square of the strength of the current passing through it, instruments can evidently be constructed on this principle which will measure either current strength or difference of potential, produced either by direct or alternating currents, and are not liable to variation from any of the causes mentioned. Among these the voltmeter, patented by Cardew in 1886, has a prominent place. Its operation depends on the expansion of metal produced by the electric development of heat.

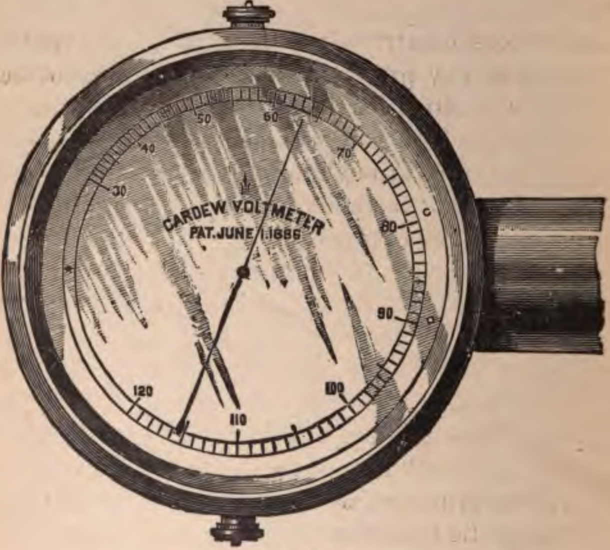

Fig. 69.

Fig. 69 gives a front view of this instrument and Fig. 70 a rear view, showing its internal construction. A fine platinum wire, 8 feet long, is stretched in four lengths in a horizontal tube, by attachment to a metal frame and pulleys, as shown at *a a t t* in Fig. 70. This tube is made of very thin metal, one third of its length being iron and two thirds brass to maintain constancy of length between the points of attachment of the wires by such a mode of connection as to produce compensation by the unequal expansion of the two metals; and the horizontal position is given it to maintain constancy of temperature, and prevent the unequal expansion, from convection of the air to which the tube and wire would be liable in a vertical position.

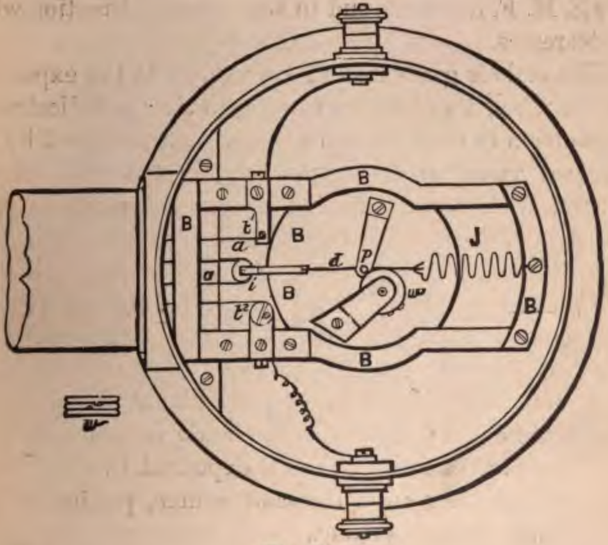

Fig. 70.

The wire has a resistance of about 240 ohms, and attains a maximum temperature of about 200° C.; and its expansion varying in a certain definite ratio dependent on the difference of temperature caused by the passage of the electric current, which, as stated, varies as the square of the current's strength, produces a variation in length proportional to the E. M. F. by which the current is generated. This produces a rotation in the pulley *w*, to the axis of which the pointer shown in Fig. 69 is attached, which moves in the same direction as watch-hands when the E. M. F. increases, and in the opposite direction when it decreases.

The scale is graduated to correspond to the expansion of the wire; its divisions varying in size, as indicated, in proportion to the variation of expansion produced by the unequal variation of temperature, in the ratio of the square, with equal variation of current strength, and consequently of E. M. F., since resistance remains constant.

This instrument should be calibrated for the average temperature of the room in which it is to be used.

THE EDISON CURRENT METER.—This is a commercial instrument constructed on the principle that the quantity of current consumed on a lamp circuit is in direct proportion to the quantity of metal deposited by electrolysis by a small current from the same source, passing at the same time, through a shunt.

Fig. 71 shows the construction. There are two cells, p, p_1, intended respectively to show the monthly consumption, and the consumption for a longer period, the one to act as a check on the other; each cell contains amalgamated zinc plates immersed in a solution of zinc sulphate, both having precisely the same construction. Underneath each is a corrugated band of German silver; the twelve corrugations at the left, marked w_2, forming the shunt through which current flows to the cell p; and the four at the right, that through which current flows to the cell p_1, which consequently receives four times the current through one-fourth the resistance.

As the deposition of metal varies with change of temperature, apparatus for equalizing the temperature, and compensating the effects of variation, becomes necessary. The general temperature of the instrument is equalized by the lamp $l\ c_1$, above which is the compound bar $f\ c$. When the temperature falls below the normal degree, this bar bends down, closing the circuit through the contacts c, c_1, and lighting the lamp: as the temperature rises, this circuit is opened by the upward bending of the bar, and the lamp is extinguished.

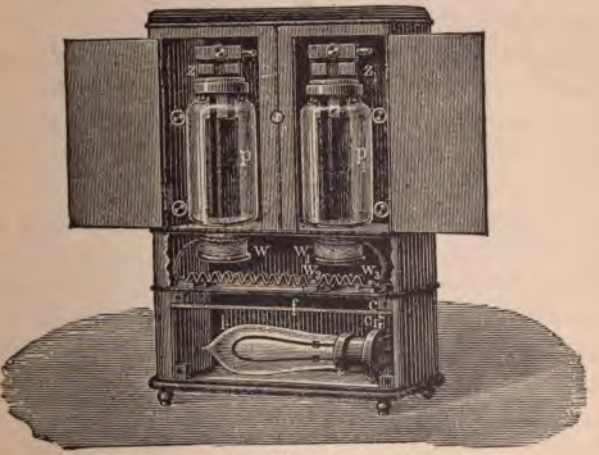

Fig. 71.

But as rise of temperature by the chemical re-action of the cells increases the conductivity of the solutions, the compensating copper coils, w, w_1, are placed in circuit under each cell respectively. The increase of current through each coil, caused by increase of conductivity in the solution, raises the temperature of the coil, and reduces its conductivity: hence, by making the length of each coil such that its temperature shall vary in the same ratio as that of the solution, compensation is effected; the rise of temperature in the coil reducing its conductivity, and diminishing the current, in the same ratio as the rise of temperature in the solution increases its conductivity, and *vice versa*.

These cells are removed and renewed at stated periods, the zincs weighed, and the amount of current consumed estimated by the amount of zinc deposited. One of the cells is accessible to the consumer, and monthly inspector; while the other is examined only by the higher inspector at the close of the longer period, and the results compared and corrected; the deposition of zinc in each respectively for the different periods being practically the same in consequence of the difference in supply of current.

THE FORBES COULOMB-METER.—Meters like the Edison cannot be used for the measurement of alternating currents; but one has been invented by Forbes, operated by the heat developed by the current, which can measure either direct or alternating currents. Its construction is shown in Fig. 72. The current passes through a flat coil of iron wire, above which is mounted, on a paper cone having a jewelled bearing at its apex, a mica disk, with mica vanes attached. The heat developed by the current produces an ascending current of air which rotates the disk, operating a light train of clockwork which moves indexes over two dials, registering the current consumption in coulombs; units being registered on one dial and tenths on the other. A glass shade protects the apparatus from external air-currents. It has never come into practical use.

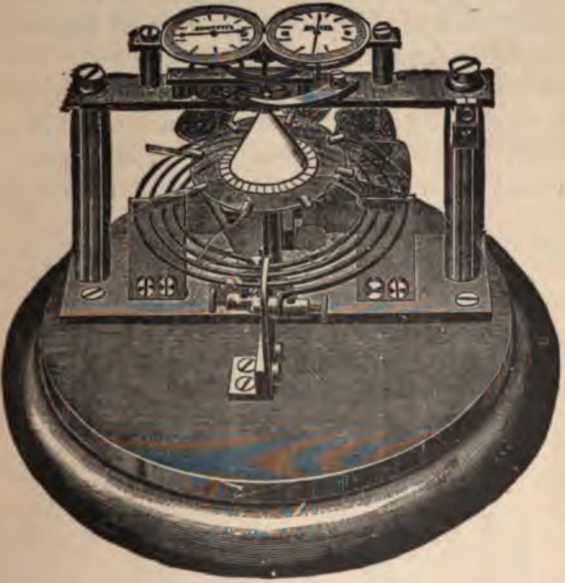

Fig. 72.

THE THOMSON RECORDING WATT-METER.—Since both E. M. F. and current strength are included in electric energy, a meter for commercial use should record their joint product as represented by the watt. Fig. 72½ shows such a meter, invented by Elihu Thomson.

Two field-coils, *A* and *B*, composed of heavy copper wire, varying in diameter from $\frac{1}{8}$ of an inch upward, according to the required capacity of the meter, are mounted as shown, about $\frac{3}{4}$ of an inch apart. They are wound without cores, both in the same direction, in series with each other and with the electric mains; the winding being in vertical planes, parallel to the open ends, and hence at right angles to that of the exterior cloth covering shown in the cut.

They inclose a drum armature of the Siemens type, seen through the opening on the left, composed of eight to sixteen coils of fine copper wire wound vertically, in a closed circuit, on a light frame of non-magnetic material, and mounted on a vertical shaft, the terminals

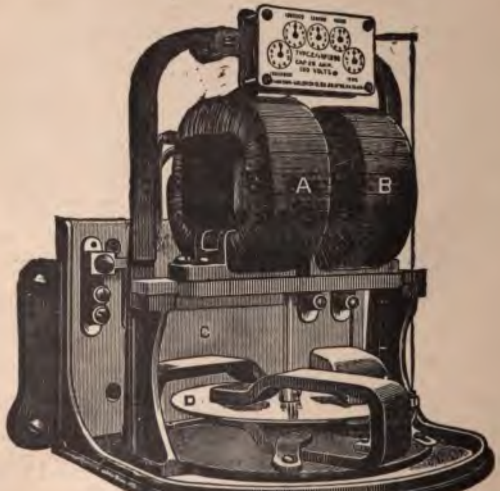

Fig. 72½.

of each coil being attached to adjacent segments of a silver commutator, mounted on the shaft just above the armature.

The field-coils, being in series with the mains, carry a current of the same strength, while the armature, which is on a fine wire shunt between the mains, carries only a small percentage of this current, representing the E. M. F. at this point, and equal, at average normal electric pressure, to about $\frac{1}{13}$ to $\frac{1}{10}$ of an ampere, but varying according to pressure and capacity of meter. Hence the mutual induction of the two currents represents the joint product of E. M. F. and current strength, the two factors of electric energy included in the watt.

The shunt current enters and leaves the armature by two silver-tipped copper springs which constitute the brushes, and press against opposite segments of the commutator on the neutral line between the field-coils, as in the dynamo; rotation of the armature being produced by the magnetic polarity induced in the field and armature coils respectively, as in those having iron cores. This polarity is similar on adjacent sides of the field and armature, and opposite on opposite sides; hence each half of the armature is repelled from that side of the field having similar polarity and attracted to that having opposite polarity; and the direction of the current in each armature-coil being reversed by the commutator, on the neutral line, at each half-revolution, the rotation is made continuous. The mode of action is the same as that of the electric motor, or reversed dynamo, current producing rotation, instead of rotation producing current as in the dynamo.

As reversal of current in the field-coils would produce corresponding reversal in the armature coils, the relative direction of current in each, and hence the relative polarity, would remain the same, producing rotation in the same direction as before reversal. Hence an alternating current produces continuous rotation in the same manner as a direct current, reversal being simultaneous in the field and armature.

The shunt current traverses a german-silver resistance coil in the back *C*, by which its strength and relative E. M. F. may be varied inversely as required; and in meters designed for circuits of very high potential, as 1000 volts, it passes also through a small transformer by which its E. M. F. is reduced.

The shunt circuit being connected to the mains between the field-coils in most of the meters, its current traverses the armature in series with that of the field-coils, instead of in parallel, as it would if the shunt connections were outside of the field-coils; and a slight additional strength of field, and hence of rotary force, is thus gained, which is of importance in compensating friction at low speed of the armature, when the ratio of friction to rotary force is large.

The armature rests in a jewelled bearing, by which its friction is reduced to a minimum. Near its upper end it carries an endless screw which engages a train of gearing by which five pointers are rotated, at different rates of speed, over dials having ten divisions each, recording the energy consumed in watt-hours, on a decimal scale, ranging from 10,000,000 on the left-hand dial to 1000 on the right-hand dial; each indicating a decimal part of that indicated on the next preceding dial to the left. A watt-hour represents the electric energy of a current of one watt flowing for one hour, or its equivalent for any fraction of an hour, as a ten-watt current for a tenth of an hour.

Attached to the shaft, near its lower end, is a copper disk, *D*, which rotates between the poles of three magnets, generating an opposing force by which the speed of the armature is limited and controlled, and which varies as the number of lines of force cut by the disk per unit of time, and therefore in the same ratio as the speed. This prevents excessive speed, also speed due to mechanical momentum in excess of electric energy, and puts the apparatus under the control of opposing forces generated solely by the electric energy, and therefore correctly representing it.

By increasing or diminishing the distance of the magnets' poles from the centre, the retardation can be correspondingly increased or diminished, and the speed regulated as required in calibration. Magnetic loss can also be thus compensated when recalibration is required. This loss is slight, however, as the constancy of the magnets is improved by a special seasoning before they are put in use.

These meters vary in minor details of construction, with reference to their capacity and the use for which each is designed; and they are thus adapted to different systems of electric distribution, and to direct or alternating currents; those intended for direct currents requiring non-magnetic frames. They range in current capacity from 10 amperes to 150, and in potential capacity from 50 volts to 2000.

MEASUREMENT OF ELECTRIC RESISTANCE.—Since current strength depends on the mutual relations of electromotive force and resistance, it is evident that apparatus for varying resistance by the introduction or withdrawal of a definite known quantity, and of ascertaining and measuring it when unknown, in order to properly adjust these mutual relations, is a matter of the highest importance in electrical construction. Resistance may be varied, as already shown, by varying the length or diameter of the conductor, or by changing the circuit from series to parallel or the reverse; but as this usually requires permanent construction, it becomes necessary to have also some simple means by which a resistance of known amount can be properly introduced into any circuit or withdrawn from it without interference with the permanent construction: this is furnished by the *resistance coil*, or rheostat, as it is also termed.

RESISTANCE COILS.—Resistance coils are made of german-silver wire on account of its high resistance, which is usually about seventeen times that of pure copper~~, and~~ calibrated as to gauge and length for a given number of ohms resistance, the wire being properly wrapped for insulation. Fig. 73 gives an ideal view of the construction.

X, *Y*, and *Z* are short blocks of brass, insulated from each other above, but connected below through the coils *c* and *d*, as shown; each coil being wound with a double strand to reduce self-induction. Two brass plugs, *a* and *b*, having hard-rubber handles, fit into holes between the blocks, so that when placed as shown, the three blocks are in electric connection, and having practically no resistance, a current would pass directly through them, without traversing the coils. But if a plug, as *a*, is removed, the current between *X* and *Y* must then pass through the coil *c*.

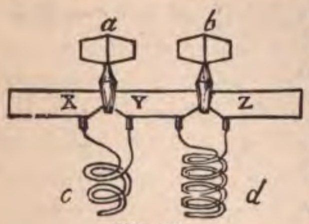

Fig. 73.

In like manner if plug *b* is removed, the current between *Y* and *Z* must pass through the coil *d*; which, being twice the length of *c*, would have twice the resistance if made of wire of the same gauge, or four times the resistance if also the cross-section of the wire was one half that of *c*. In this way resistance can be varied to any practical extent required.

Sets of resistance coils, calibrated for resistance varying from 1 ohm or less to 10,000 or more, are conveniently arranged in cases, as shown in Fig. 73½. The case has a hard-rubber cover by which the brass blocks are insulated above, each pair being connected through a coil below, as shown in Fig. 73. A hole in the centre of each block receives each plug when removed from between the blocks, to prevent its being mislaid, and connection with the electric circuit is made through the binding-posts shown at the right.

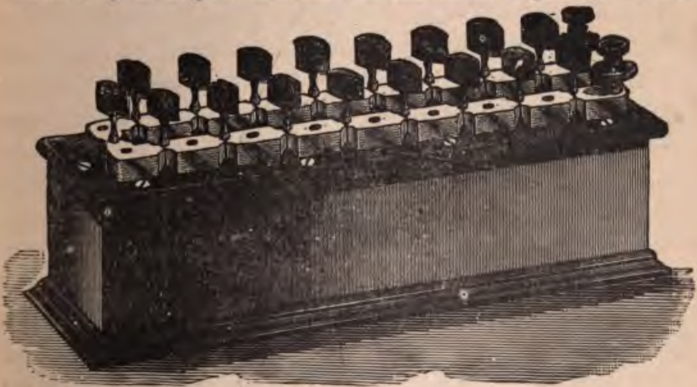

Fig. 73½.

To introduce any required resistance it is only necessary to remove the plug from its place between the blocks opposite which the resistance required is marked on the cover, the other plugs all remaining connected. If, for instance, 1 ohm resistance is to be introduced, let the first plug at the front right-hand corner be removed, opposite which "1 ohm" is marked; the current must now flow through that coil, and pass by all the other coils, through the blocks and plugs; if 50 more ohms are to be added, the last plug at the rear left-hand corner is removed, opposite which is marked "50 ohms;" and the resistance then becomes 51 ohms.

THE STANDARD LIGHT UNIT.—The illuminating power of a lamp is determined by the photometer, by comparison with a standard unit of light. This standard varies in different countries. In France it is the Carcel lamp, in which pure colza oil is burned; the wick being 30 millimeters in width, and the flame 40 millimeters in height. The German standard is a paraffin candle, 20 millimeters in diameter, having a flame 50 millimeters in height. The English standard is a sperm candle, burning 120 grains per hour. The Paris Electric Conference of 1881 adopted as a standard unit the light radiated by a centimeter of pure melted platinum at the temperature of congelation. A platinum strip 5-6 millimeters wide is inclosed in a metal box having a conical opening of 1 square centimeter at its narrowest part, and is brought to the point of fusion by a battery current; the radiated light being just one-tenth that of the standard unit. A lamp or candle whose illumination has been determined by this unit, can be most conveniently used in practice.

THE BUNSEN PHOTOMETER. — Every photometer is constructed according to the well-known law, that the intensity of light varies inversely as the square of the distance; the light being received by the instrument at a certain definite angle. Of the various instruments of this kind in use, the Bunsen is one of the simplest and most practical. A convenient style of this instrument consists of a narrow box about forty inches in length, with sliding shutters on one side: in it is placed a little screen of oiled paper mounted on a movable frame between two mirrors, at equal angles to both, so that an illuminated spot on the screen can be seen at the same time in both mirrors. This screen, with the mirrors, slides longitudinally, and can be moved to any required point on the central axis of the box, and inspected through an opening in the shutters. The standard light is placed in one end of the box, and the light to be measured in the other end, air holes being provided above each. The screen is then moved to a point where the intensities of the opposite lights, as seen by their reflected images in the mirrors, are equal, which requires careful adjustment till the variation in illumination is equalized. The exact distance of each light from the screen being shown on a graduated scale, the illumination of the light under measurement, as compared with the standard, is determined by the law given above. If the distance of an incandescent lamp from the screen is four times that of a standard candle, then the candle power of the lamp is $4 \times 4 = 16$ candle-power.

If an arc light is to be measured, the required distance from the screen being too great to admit of the use of the box, the measurement must be made in a darkened room of sufficient length.

CHAPTER VII.

THE ARC LAMP.

PRINCIPLES OF THE ARC LAMP. — The production of light and heat by the electric current depends primarily on the strength of the current, and on the resisttance which it encounters; the development of heat in a conductor, according to Joule, being proportional to its resistance, to the square of the strength of the current, and to the time the current lasts. We have illustrations of this in the spark of the electric machine and in the lightning's flash, both of which result from the resistance of the air to the passage of electricity. Heat is always a result of this resistance, even in the best conductors, and precedes the production of light; but the resistance encountered in such conductors as copper and iron is not sufficient, except with currents of abnormal strength, to raise the molecular intensity to the degree requisite for the production of light. The case is analogous to that of the production of heat by friction, where heat development is in the inverse ratio of heat conductivity: friction between wooden surfaces rapidly produces combustion, the effect being, from want of conductivity, concentrated on the points in contact; while from the conductivity of metals the heat developed by the same amount of friction is distributed through the mass, and the temperature developed at the points of contact proportionally reduced, the proportion depending on the conductivity of the metals. Similarly, what takes place on the surface in mechanical friction may be assumed to take place throughout the mass in the molecular action which we term electricity. And if, as we have assumed, electric conductivity depends on molecular arrangement, the internal friction between the molecules must be greater in an abnormal arrangement, such as may be assumed to exist in substances of low conductivity, than in the normal arrangement assumed to exist in those of high conductivity. Hence the choice of a substance having the proper proportions of conductivity and resistance combined with other necessary qualities becomes an important consideration in the construction of the electric lamp.

There are two methods of producing the light, one depending on the combustion of the light-producing substance, and the other on its incandescence; and these methods have given rise to two systems known respectively as the arc light and the incandescent light systems. The arc light is the oldest, and originated with Sir Humphry Davy in 1813; and it is remarkable that carbon, the substance in common use in the modern electric lamp, was the substance which he adopted in those early experiments; and the construction of the modern lamp has for its principal basis the same fundamental principles which he discovered and adopted. Passing a current furnished by a battery of 2,000 voltaic cells through two rods of common wood charcoal, placed end to end, he obtained, on slightly separating them, a light of intense brilliancy and heat, having the form of an arch, or arc of a circle; hence the term voltaic arc, designating both the origin and form of the light, the latter word being still retained, while the former has fallen into disuse since the battery, as a generator for lighting purposes, has been superseded by the dynamo.

The contact of the carbons is necessary for the establishment of the current, and their subsequent separation for the production of the light. The ordinary current which maintains the light is not strong enough to pass through an air space of even $\frac{1}{100000}$ of an inch; but the current produced by the separation of the carbons after contact is far more powerful, resulting from the difference of potential caused by the sudden accumulation of energy on the positive side of the break, and the negative condition on the opposite side: a film of carbon is volatilized by this powerful current, and the space between the carbons filled with carbon vapor, which is a partial conductor of very high resistance. The combustion of this vapor, and of the carbons themselves by the union of oxygen, heats the air, and reduces its resistance, so that the current is maintained in this heated air and vapor at its normal strength through a resistance varying from ½ an ohm to 100 ohms, and across an air space of $^1/_{16}$ to ¾ inch. The light is of intense brilliancy, varying from 1,000 to 2,000 candle-power, being greatest on the surfaces of the carbon points, especially on that of the positive carbon; while the heat, which is also of great intensity, is greatest in the carbon vapor, and capable of volatilizing the most refractory substances, not excepting even the diamond.

The direct current is usually preferred for the arc light, and the vertical position for the carbons; the current passing from the upper to the lower carbon, as shown in Fig. 74. The upper, or positive, carbon is consumed about twice as rapidly as the lower, or negative, carbon; and the exterior of both more rapidly than the interior; consumption increasing toward the tips, producing a cone on each, the lower pointed, and the upper truncated, with the formation of a crater at the tip. The light, being the most intense on the upper carbon surface as stated, emanates chiefly from this crater, and is radiated downward; the amount thus radiated being equal to about sixty-five per cent of the entire light produced. This is the principal reason why the direct current is preferred for arc lighting; illumination, except in special cases, being wanted below *rather* than above or in a horizontal

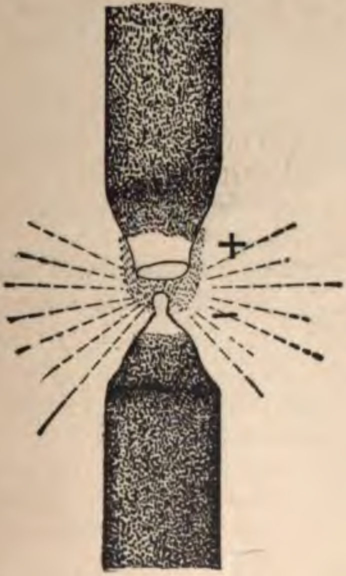

Fig. 74.

direction, especially from arc lights, which, from their intense brilliancy, and the powerful currents which they require, must be elevated for safety.

With the alternating current, both carbons are consumed at the same rate, and both retain the pointed form, which permits a free radiation of the light in nearly every direction. For lighthouse illumination, there is an advantage in this; and by reflectors and lenses, the light can be concentrated and intensified in a given direction. While there would seem to be an economical advantage in the equal consumption of the carbons by the alternating current, it has been ascertained by experiment that the carbon wastage is much less with the direct current.

In short arcs, particles of carbon and fused impurities are deposited on the lower carbon, forming the *mushroom tip* shown in Fig. 74, which is burnt off at the base and again renewed, as the consumption proceeds. This deposit does not occur in long arcs.

The flame assumes the form of an arc from the fact that the electric potential of the space between the carbons is much higher than that of its surroundings, including the air and external objects; consequently the incandescent vapor is repelled from this space by virtue of equality of potential within the space, and attracted outward by virtue of difference of potential between the space and its surroundings; and the flame being connected with the carbons above and below, the central part alone yields to this outward pressure, producing the arc.

Since the alignment of the carbons is not exact, nor the surfaces in contact perfectly flat, the flow of the current before separation is liable to be through points at one side of the center; and after separation and the formation of the crater, the line of least resistance is evidently between the point of the lower carbon and the lowest point on the edge of the crater. The highest potential is evidently through the center of the flame, where the principal part of the current is flowing; and the outside potential being lower than the potential at any point between the carbons, the flame bends out to one side, instead of equally on all sides, and forms an arc; whereas, if the current were perfectly central, and the outward pressure perfectly equal on all sides, the flame would be a spheroid.

As each lowest point on the edge of the crater is consumed, and the distance, and consequently the resistance, is increased, the flame shifts to the next lowest point, and so travels round the edge of the crater while pivoted on the point of the lower carbon.

As an electric current can be attracted or repelled by a magnet, this flame-bearing current exhibits the same effects; and the arc can thus be increased or diminished by the approach of a magnet, and also be attracted by the approach of an unmagnetic body of different electric potential.

ARC LIGHT CARBONS. — As the efficiency of the electric light depends very largely on the carbons, it is of the highest importance that they should be properly prepared; hence not only the materials of which they are composed, and the methods used in their preparation, require careful consideration, but their length, diameter, conductivity, resistance, and other points, are also matters of the utmost importance in securing the best results.

As already stated, wood charcoal was the substance employed by Sir Humphry Davy; but this in its ordinary state is unsuitable, being soft, porous, and rapidly consumed, with a deflagration troublesome and dangerous: it therefore became necessary to find some form of carbon which would consume slowly, and give a steady, brilliant light. The carbon cut from the interior of gas retorts, was proposed by Foucault, and was found to fulfill these conditions to a certain extent; but its impurity, and lack of homogeneousness, interfered seriously with the quality and steadiness of the light, though, for want of something better, it was used in all the early experiments; but it became evident that carbons specially prepared for this purpose were required, and this requirement became the more imperative when electric lighting, by the invention of the dynamo, was made a commercial success. Various experiments by different European inventors finally resulted in the production in France of the carbons of Carré and Gaudoin, which were the first to fulfill approximately the required conditions of purity, homogeneity, proper resistance, and proper form.

Previous experiments in this direction by Lacassagne, Thiers, and others, had been made in 1857 and subsequently, by pulverizing and purifying the carbon, making it into a paste, molding and baking it. One of the early methods of Gaudoin was to use rods of wood charcoal, similar to those employed by Davy, infiltrate them with various hydrocarbons by repeated soaking and baking alternately till they had attained the necessary consistence as indicated by their metallic ring.

The Carré carbons, which still maintain a high standard of excellence, are now made as follows: Fifteen parts of pure coke finely pulverized, and five parts of calcined lampblack, are mixed with seven to eight parts of a syrup made of cane sugar and gum arabic, in the proportions of thirty parts of sugar to ten parts of gum. The mixture is then pulverized, made into a paste with water, forced under heavy pressure into a die of the form required for the carbons, and baked repeatedly at a very high temperature. After each baking the carbons are immersed in a concentrated syrup of burnt sugar, maintained at a boiling temperature, so as to fill the pores with the sugar, the process being facilitated by intervals of cooling; and the superfluous syrup being washed from their surfaces with boiling water previous to each baking. When the required density is attained, the carbons are slowly dried for about fifteen hours at a temperature of about 170° C., and are then ready for use. Great tenacity is one of the good qualities claimed for these carbons, and they can be used in lengths of twenty inches without risk of fracture.

The Gaudoin carbons are made from carbon obtained by the destructive distillation, in closed graphite crucibles, of tar, bitumen, pitch, oil, and other substances; all foreign matter being expelled, leaving a residuum of nearly pure carbon.

This is reduced to a fine powder, made into a paste, and the carbons formed under a high pressure.

Napoli, another French manufacturer, makes his carbons from a coke obtained from the slow distillation of coal. This coke, after being pulverized and screened, is mixed with gas tar, in the proportion of seventy-five per cent of the coke to twenty-five per cent of the tar. The carbons, after being formed, are first baked at a low temperature, not exceeding that at which the coke and tar were produced: after cooling they are baked again at a white heat, which removes all traces of gas, producing carbons of great hardness, ready for use without further treatment, which are said to give a steady, pure white light at a slow rate of consumption.

In the manufacture of the Liepmann carbons, made in London, the raw material is obtained from the distillation of mineral oil, which, it is claimed, contains only carbon and hydrocarbons, and furnishes carbons free from the impurities found in those made from coke, graphite, or retort carbon, which produce the colored tints and flickerings in the light, and the troublesome ash deposit. The material is soft and brittle, and easily pulverized. It is first ground to a fine powder, then baked, and subsequently mixed with a specially prepared tar, and the paste thus formed, molded into carbons. The molding is done under a pressure of about thirteen thousand pounds to the square inch, obtained from a hydraulic accumulator in connection with a steam-engine and pump. The carbon rod, squirted endways through a die, issues continuously upon a table moved on rollers; and, when a length of four feet is attained, it is cut into twelve-inch lengths by four knives carried in a frame. The carbons are then stacked, with carbon dust between the layers to prevent adhesion, dried in the air for several weeks, and then straightened by being rolled between boards, after having been sufficiently heated to render them plastic. Two kinds are prepared in this way, — the solid carbons, and the shells for cored carbons. These shells are closed at one end, and the cores injected by a small hydraulic press.

The baking, which is an exceedingly important and delicate operation, is done in gas-heated furnaces in which the heat can be kept under perfect control. The carbons, stacked upon an iron trolly, are slowly passed through the principal furnace, which has five zones of heat: they enter through the coolest zone, and emerge through the hottest, and then pass into an auxiliary furnace, the temperature of which is reduced very slowly. They are then finished by trimming the ends, and copper plating such as require it, and, after being tested for resistance, are ready for use.

The testing is accomplished by an automatic machine, electrically controlled, through which the carbons are passed; each one being momentarily inserted in a shunt to a solenoid. The required resistance of a carbon being about two-tenths of an ohm, if the resistance exceeds this, the carbon is held, carried forward, and dropped into the box of rejected carbons; but if the resistance is less, permitting a greater flow of current through the carbon, the current through the solenoid is reduced; and by means of a spring, which opposes the attraction of the solenoid, the carbon is released, and drops into another box.

The copper plating is accomplished by an apparatus having eight sliding frames, each carrying a row of spring clips by which the carbons are suspended, and under each frame a glass vessel containing dilute sulphuric acid in which a copper cylinder is immersed; this cylinder forms one of the electrodes; and the frame, when lowered and immersed in the liquid, forms the other. The current is furnished by a dynamo, which also supplies the current for the testing machine, connection being made by an automatic switch when the frame is lowered; and the time required for plating is indicated by the color of the deposit.

In the United States the material now used in the manufacture of arc light carbons is petroleum coke, a residuum of the distillation of crude petroleum, which contains very little foreign matter that cannot be expelled by heat. This is ground and mixed with some hydrocarbon, generally gas-house pitch, and the mixture then ground again. It is then placed in steel molds of the proper form, twelve inches long, and heated sufficiently to render it plastic, after which it is subjected to a hydraulic pressure of from 3,000 to 8,000 pounds to the square inch; the amount of pressure depending on the purpose for which the carbons are intended. They are then baked at a high temperature for 24 to 100 hours, according to the style of furnace, and number of carbons placed in it. The crooked carbons are then culled out, and the straight ones electroplated.

It has been shown that the arc light is derived from incandescent carbon, and carbon vapor; also that, in the process of manufacture, various hydrocarbons are used, both in the original composition and in the subsequent process of infiltration, after which the carbons are again baked at a high temperature; the object of the infiltration being to produce density, and of the subsequent baking to reduce the hydrocarbons to pure carbon by expelling the other constituents.

It is found that the intensity of the light is in the direct ratio of the temperature of the arc; and, since pure carbon requires for its volatilization the highest temperature of any known substance, it is evident that this intensity depends on the purity of the carbon, any *remaining* foreign substance becoming volatilized at a lower temperature, and interfering seriously with the intensity of the light. It is shown by the spectroscope that the whiteness and purity of the light depends, like its intensity, on the purity of the carbon; and it is also found that the resistance of the arc is in the same ratio; its resistance being at the maximum, and its conductivity at the minimum, with the maximum of purity in the carbon. The distance between the carbons, as will be shown hereafter, is regulated automatically by this resistance, being shortest when the resistance is greatest; and the consumption of the carbon is, at the same time, at the minimum. Hence it follows that the highest economy of consumption, and the best light is attained with the greatest purity of the carbon.

As the vapor resulting from the volatilization of foreign substances has higher conductivity than carbon vapor, there is often, with impure carbons, a sudden lengthening of the arc and reduction of the light, caused by the consumption of this foreign material. the carbons automatically adjusting themselves to the reduced resistance, and again returning to their normal distance, and the light to its normal intensity and purity, when the foreign matter is consumed; the net result being a flickering, unsteady light, varying from a short arc of intense brilliancy to a long colored arc of perhaps one-fourth the brilliancy, and returning again to the intense white arc.

Another serious defect is the lack of homogeneousness of structure, even with purity of material; the density at the ends may vary materially from the density at the center, producing an irregular rate of consumption; or dense carbon may be infiltrated throughout with soft carbon, the soft carbon consuming more rapidly, producing numerous small craters, and leaving ridges of hard carbon, resulting in a noisy, inconstant light. Carbons molded by side pressure are less liable to the first defect—difference between the density of the ends and center — than those molded by end pressure, and subsequently cut into lengths; and the latter method has been generally abandoned in favor of the former in American factories, as it was found impossible to apply end pressure with proper uniformity. Carbons with the cores injected into shells of greater density, burn more rapidly in the center than at the edges; and hence the form of the crater is more perfect, and the liability to the second defect — small craters surrounded by hard ridges — is greatly reduced. This defect can also be overcome by proper care in the preparation of the paste.

Carbons require to be perfectly straight and cylindrical, and of perfectly uniform diameter from end to end; and those of the length required for the usual long periods of continuous consumption are liable to defects in one or more of these respects in the various processes of manufacture. Good contact with the carbon holders, and proper alignment of the two carbons, is impossible with those of defective form; and such carbons are a constant source of annoyance, no matter how great their excellence as regards purity and density.

The electric resistance of the carbons is also a point of the highest importance, especially on a circuit having a large number of arc lamps in series; and here again the purity of the carbons becomes important, for while the resistance of the incandescent vapor which constitutes the arc increases with the purity of the carbon, as has been shown, the resistance of the carbons themselves diminishes; the purest and densest carbons having the lowest resistance. Plating with copper, iron, or nickel, for the purpose of reducing resistance, has been tried with varied success, also embedding iron wire in the center of the carbons. The principal objection to copper plating is, that with the direct current, the carbon of the negative rod is consumed more rapidly than the copper, leaving a copper fringe which casts a shadow; but, notwithstanding this objection, it is generally adopted as the best means of reducing resistance. Carbons for lights not exceeding 1,200 candle-power do not require plating, while those for lights of 2,000 candle-power and upwards are always plated.

The ordinary length of carbons, as already stated, is 12 inches; but the diameter varies according to the strength of current and candle power of the light for which the carbons are intended, ranging from $^7/_{16}$ inch with a 6.8 ampere current, and a 1,200 candle-power light to $^9/_{16}$ inch, with a 15 ampere current and a 3,000 candle-power light. For a 2,000 candle-power light with a 10 ampere current, the diameter of the carbons is $^7/_{16}$ to $^8/_{16}$ inch; while for exceptionally powerful lights, such as are required for lighthouses, and search lights on steamers, carbons exceeding an inch in diameter are required.

The principle which underlies this is the ratio of molecular action to the mass of the carbon. If the mass is too small for the amount of current, the molecular action is too much concentrated, and the carbon either wastes away by becoming heated through from end to end, or there is an imperfect formation of the crater, the edges consuming too rapidly, allowing upward radiation, and consequent practical loss of light. But if the mass is too large for the current, the molecular action is too much diffused, producing a dull red light in the outer portions of the carbons instead of an intense incandescent glow; the point of the lower carbon also becomes too obtuse, causing too great lateral radiation, and a broad shadow underneath. With the proper proportions between the amount of current and the diameter of the carbon, the increase of light is in the direct ratio of increase of diameter; powerful lights requiring carbons of large diameter, while smaller lights require those of less diameter.

THE JABLOCHKOFF ELECTRIC CANDLE. — Among the earlier methods of producing the electric light was the candle invented by Jablochkoff, a Russian military officer, in 1872, about five years subsequent to the invention of the Gramme dynamo; and its use had been continued up to a comparatively recent date, 2,500 of these candles being used in Paris for street lighting as late as 1880; and though finally superseded by better methods, it will always possess a historical interest on account of its success and popularity in the early history of electric lighting.

Its construction is exceedingly simple, consisting of two carbon rods, each about 8.33 inches in length, and $^1/_6$ inch diameter, mounted vertically, side by side, on a base, at about $^1/_{16}$ of an inch apart, and insulated from each other by a composite substance, of which kaolin — porcelain clay — is the principal ingredient; which also forms an attachment between the carbons, and produces the effect of the lime light as it consumes in connection with them. The candle thus formed is supported on the base in a double spring clip through which the current enters, passing up one carbon and *down the* other, the upper extremities being connected by a strip of graphite or other carbonaceous substance, which acts as a primer through which the current passes to establish the arc, and is consumed in the process, the current being subsequently maintained through the arc in the usual manner; hence if, through accident, the light becomes extinguished, it cannot renew itself.

As equal consumption of the carbons is an absolute necessity with this candle, it can be used only with the alternating current. Each candle lasts about an hour and a half; and lamps are constructed containing several candles, and furnished with apparatus by which the current can be changed automatically from a burnt-out candle to a new one, each having a separate connecting wire; while one common wire is used for the return current. Hence a lamp containing six candles furnishes light for nine hours.

The required horse power on a circuit of five candles is 1.57 per candle, with ten candles 1.27, and with twenty candles .92; and the illumination of each light, without globe, 400 candle-power. It is evident that since the crater of the positive carbon, as well as the point of the negative, faces upwards, there must be, with this system, a great waste of light from direct upward radiation. The incessant variations of tint and brilliancy in the light, and the noise produced by the alternating current, has of late aided to bring this system, once so popular, into disrepute.

THE JAMIN ELECTRIC CANDLE. — The loss of light from upward illumination with the Jablochkoff candle, and the lack of means for relighting automatically when accidentally extinguished, led to the invention of electric candles free from these defects, among which we find the Jamin candle, which is represented by Fig. 75.

Two carbons, k k_1, $^1/_5$ inch diameter, are suspended point downwards, and surrounded below by a flat copper coil inclosed in a light case of copper foil, g g g g, which is attached to an insulating slate, p p, through which the carbons pass. The carbons are inclined at a slight angle so as to bring their points together, k being fixed, while k_1 is movable, and connected with a spring armature f by a pin s; the armature being attached to the case below, and slightly separated from it above. The coil is included in the electric circuit with the carbons; and when the current passes, the armature f is attracted, and k_1 separated from k by the pin s a sufficient distance to form the arc; the carbons, as consumed, being lowered by a wheel train inclosed in the tube shown above. Should the light become extinguished, the current being interrupted, the attraction of f ceases, and the retractile force of the spring brings the points of the carbons together, and renews the arc. A glass globe attached to p p incloses the lower part of the apparatus.

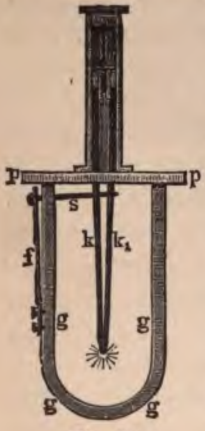

Fig. 75.

A pair of carbons lasts about two hours; and lamps are constructed with several pairs, and an arrangement by which, as each pair burns out, it consumes a fine brass wire which releases a spring by which the current is instantly changed automatically to the next pair; so that lamps constructed with three candles burn continuously for six hours without attendance. This candle, like the Jablochkoff, requires the alternating current.

THE SUN LAMP. — This lamp, invented by Clerc and Bureau, is illustrated by Fig. 76, and combines in its construction the arc and incandescent systems. To a metal frame g g is attached a block of marble or condensed magnesia, M M M, ⅜ to ¾ inch thick, through which the carbons k k are transmitted, and by which also they are insulated; the form of the opening through which they pass being so shaped that as they slide down by their own weight, or that of weights attached above, as they are consumed, they are prevented from passing through; their points entering a cavity in which the light is produced.

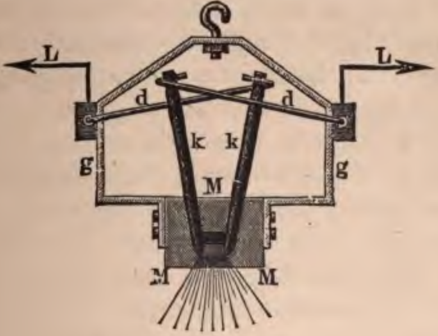

Fig. 76.

They are attached above to the conductors d, d, insulated as shown, and connected with the electric circuit L, L. A primer, connecting the points of the carbons, establishes the arc; after which, current is maintained through the block, which becomes a conductor by being heated between the carbon points. The arc is of exceptionally great length, varying from .39 of an inch to 2.36 inches, while, in the ordinary arc lamp and Jablochkoff candle, it is only $^1/_{16}$ to $^1/_8$ of an inch in length. The luminous point is fixed, and the light remarkably steady. It has a yellow tint when marble is used, and is of great intensity; the light being largely due to the incandescence of the lime formed from the marble, while the magnesia block produces a white light. Marble blocks last for two lighting periods of about ten hours each, the durability being reduced by the heating and cooling with shorter periods. The carbons vary in length from two to twelve inches, and last about fifteen hours.

The blocks vary in thickness, according to the requirements of the light, being made thinner for short circuits and strong currents than for long circuits and currents of less volume and greater intensity. Those made of condensed magnesia are more durable than those made of marble, being capable of lasting a hundred hours.

The alternating current is preferred for this system, the lamp being closed to suppress the noise. The light is radiated downwards; but upward or horizontal radiation can also be obtained, springs being used to push the carbons. In another form of the lamp the carbons are placed horizontally, and have a special device for automatic relighting. The system is said to be economical, and the light, depending largely on the incandescence of the marble or magnesia, but slightly affected, even by considerable variations of current strength.

AUTOMATIC ADJUSTMENT OF ARC LIGHT CARBONS. — The automatic adjustment of the carbons is the main point in arc lamp construction, as upon this depends the production of the light, its renewal in case of extinction, and, to a considerable extent, its constancy and steadiness. This adjustment, consisting in separation and approach of the carbons, is operated and controlled by the electric current which creates the light. by various methods, as a train of clockwork, a break wheel or clutch operated by an electro-magnet, or a solenoid. The applications of these methods are numerous, and have led to the invention of a great number of different lamps. If the adjustment of the carbons in a single lamp were the only requirement, the problem would be comparatively easy; but the placing of a large number of lamps on one common circuit, and so regulating the resistance and the supply of current that each shall furnish an even, steady light, without interfering with the others, is a far more intricate and difficult affair. This regulation of a number of lamps on a common circuit is accomplished by the method originally proposed by Hefner von Alteneck, by which the regulating apparatus is placed in a shunt instead of in the main circuit; the shunt, which has a high resistance, causing the approach of the carbons, while their separation is produced by a coil of low resistance placed in the main circuit.

The length of the arc is a very important matter. If too long, the intensity of the light, as well as its constancy and steadiness, is reduced, and the resistance abnormally increased. If too short, there is a decrease of intensity from insufficient resistance, and a wastage of the current from too great conductivity, the light obtained being less than the current can furnish. The length of the arc must also be adjusted to the amount of illumination for which the lamp is intended; and it is found, that, for lamps of 1,200 candle-power, the most practical length is about $^1/_{16}$ of an inch; while, for those of 2,000 candle-power, it should be about $^1/_8$ of an inch.

THE FOUCAULT-DUBOSCQ LAMP. — The first arc lamp with automatic regulation was invented by Foucault, and subsequently improved by Duboscq, and was constructed with clockwork, operating by gearing; two vertical racks being connected with the carbon holders, and controlled by an electro-magnet and opposing spring in such a way, that, while the spring tended to bring the carbons together, the current which produced the light, passing through the electro-magnet, attracted an armature which tended to separate them, the carbons being placed vertically. The clockwork was operated by springs which required to be wound like those of a clock. Either the constant or alternating current could be used, the feeding forward of the positive carbon being proportional to its increased consumption with the direct current.

THE SERRIN-LONTIN LAMP. — The construction of this lamp, invented by Serrin, and improved by Lontin, will be understood from Fig. 77.

The carbons, not shown, are placed vertically in the usual manner, and connected above with the holders n and h_1 h_2, the upper + carbon with n, and the lower — carbon with h_2 which moves vertically inside of h_1. A rack connected with n engages a gear wheel r to which is attached a wheel s, with which is connected a chain which passes over a pulley, and is attached to a support t, connected with the holder h_2; hence, as n descends by its weight, it raises h_2, and the carbons approach each other.

A frame, *a b c d*, hinged at *a* and *c*, but having a free vertical motion at the side *b d*, is connected with the clockwork by the gear wheel r_1, and kept in equilibrium by three spiral springs, two below and one above a transverse bar connecting it with the support *t*. A detent *z*, attached to this frame, releases the gear wheel *r*, permitting the motion of the clockwork, which brings the carbons together as described, in consequence of which a slight lowering of the frame occurs, and the detent *z* stops the clockwork. An electro-magnet *e*, placed in circuit with the carbons attracts an armature *a*, connected with the frame, when the current passes, drawing down the frame and the holder h_2 connected with it, separating the carbons, and establishing the arc. If the arc becomes abnormally long, the increased resistance reduces the current, and lessens the attraction of the armature, the springs raise the frame, pushing up the lower carbon, and the detent being at the same time released, the clockwork is put in motion, and the carbons brought closer together. By this series of adjustments the arc is maintained at its normal length. By a screw s_1 the pressure of the lower springs is so adjusted as to produce the requisite equilibrium. By a proper

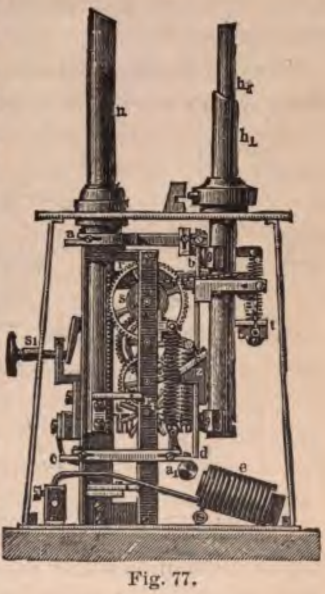

Fig. 77.

New York ... ST. AGNES BR

adjustment of the gear wheel *r* and the wheel connected with it, the arc is adjusted to the required length. The current may be either direct or alternating.

THE BRUSH ARC-LIGHT LAMP. — Among the numerous excellent arc-light lamps which have been constructed, the Brush may be selected as an example of simplicity, and adaptation to the purpose for which it was designed.

Fig. 78 is an ideal illustration of the construction, from which it will be seen that the adjustment of the carbons depends solely on the attraction of a solenoid, without the intervention of clockwork or gearing. *X* and *Y* are the terminals of the electric circuit, *K* and *K′* the carbons; the lower carbon holder, connected with *Y*, has a fixed position; while the upper holder, connected with *X*, is free to move vertically. This movement is produced by the solenoids *H*, *H′*, each of which is wound with coarse copper wire, and placed in the main circuit by connections at *X* and *Y*. At the *right* of *X* are shown three branches, one extending

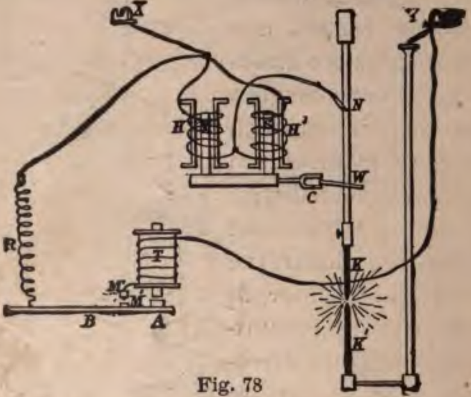

Fig. 78

to a resistance coil *R;* and the other two, after being coiled round the bobbins *H*, *H′*, re-unite, as shown, and connect with the upper holder at *N*, the connection with *Y* being through the carbons *K*, *K′*.

A shunt of fine copper wire, not shown in the cut, is connected directly with the terminals *X* and *Y*, so that the current through it does not pass through the carbons. This shunt is coiled round the bobbins *H*, *H′*, outside of the coarse wire, but in reverse order, so that the current passes through it in the opposite direction, thus partially neutralizing the magnetic effect of the current traversing the coarse wire. The shunt, having a high resistance, carries about one per cent of the entire current; but its coils being much more numerous than the low resistance coils, their magnetic effect is proportionately increased.

The carbons being in contact at the start, and the main current passing through them and through the low resistance coil, the cores of the solenoids are attracted, lifting the clutch *C*, which grips the edge of the loose washer *W*, which being tilted at an angle, as shown, grips the upper holder, and lifts the carbon *K*, forming the arc. The separation of the carbons increases the resistance in the main circuit, and in like proportion the potential difference, or E. M. F., and hence the strength of the shunt current, which by its opposition to the main current reduces the magnetic attraction, and checks the ascent of the upper carbon when the arc has attained its normal length. A reduction of resistance reverses these results, increasing the distance between the carbons. Thus, by the action of these opposing currents, the normal length of the arc is maintained; and this normal length may be adjusted as required, by varying the relative resistances of the two circuits when the lamp is constructed; so that it can be maintained at one-sixteenth of an inch, one-eighth of an inch, or any other length required by the candle power of the lamp. If a lamp becomes accidentally extinguished, the relative change of resistance in the two circuits operates to bring the carbons together, and the light is instantly renewed. Sudden fluctuations in this series of adjustments, which would produce a flickering, unsteady light, are obviated by connecting the armature of the solenoid and the upper carbon holder with pistons moving in tubes filled with glycerine, by which smoothness and steadiness are imparted to the movements.

Fig. 78 shows also a short-circuiting apparatus by which, in case of a lamp from any cause becoming permanently extinguished, it is short-circuited, so that the flow of current to other lamps on the same circuit is not interrupted. This apparatus consists of a resistance coil *R*, and an electro-magnet *T*, wound with coarse wire, placed in a direct open circuit between the terminals *X* and *Y*, as shown, through the hinged lever *B* and armature *A*. In addition to this open circuit, there is also a closed circuit of fine wire, wound on the bobbin *T*, in the same direction as the coarse wire, and forming part of the fine wire shunt of the solenoids *H*, *H′*. The ordinary current through this shunt, by which the lamp is regulated, is not sufficient to attract the armature *A*; but if the lamp should happen to be permanently extinguished, the resulting increase of current strength attracts *A*, and closes the coarse wire circuit through the contacts *M*, *M′*, so that the main current flows past the extinguished lamp to the other lamps on the same circuit.

By adapting the resistance of *R*, and the windings of the bobbin *T*, to the strength of the current, the requisite adjustment can be obtained.

The carbons, twelve inches long, last about eight hours, about three-fourths of the positive carbon and one-third of the negative being consumed. The lamps are usually constructed with either one or two pairs of carbons, but can be made with three or more pairs if necessary; and, by the simple device shown in Fig. 79, each pair is lighted in succession automatically when the pair previously lighted has burnt out. The frame *K*, which is connected with the solenoids, is adapted to two pairs of carbons. The clutch on the left is narrower than the one on the right; it consequently grips the washer W^1 and lifts the carbon-holder R^1 before the right clutch can grip W^2 and lift R^2; the current, which at first passes equally through both pairs of carbons, is now, in consequence of the separation of the left pair, diverted through the right pair alone; the frame continues to rise, the right pair are separated and the arc established.

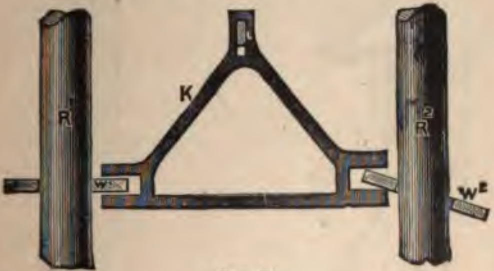

Fig. 79.

The separation of the left pair is too great to admit of the formation of the arc; but when the right pair is so far consumed that the light is extinguished, and they can no longer be brought together for relighting, the **left pair is** brought into contact, and the arc re-established automatically, less than a second being required to renew the light. Fig. 80 represents a single lamp, and Fig. 81 a double lamp; the controlling and regulating apparatus being inclosed in the circular case above the carbons.

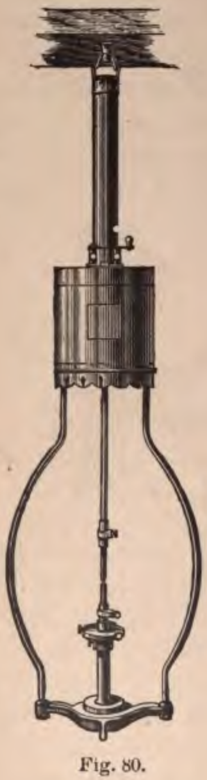

Fig. 80.

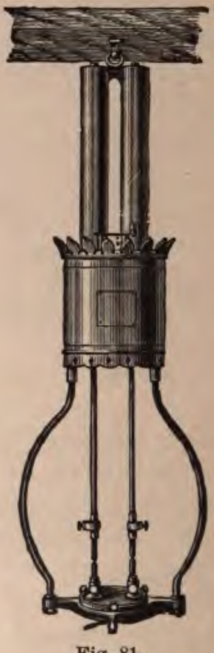

Fig. 81.

The solenoid and clutch method of automatic regulation, variously modified, is now employed in numerous arc lamps besides the Brush; the method with clockwork, or gearing, is also in common use; and the two methods are also sometimes combined.

In the consumption of arc-light carbons, cones of hal to five-eighths of an inch in length are maintained on both carbons, that of the lower carbon being pointed, while that of the upper carbon is truncated, the crater occupying about one-third of the diameter. As these cones are incandescent, light is radiated from a space, including the arc, of an inch or more in length, while the actual distance to which the carbons are separated is only one-sixteenth to one-eighth of an inch: the incandescence of the upper + carbon is more intense, and yields much more light, than that of the lower — carbon.

The Inclosed Arc Lamp.—This lamp, which came into commercial use in 1895–6, differs from the lamps already described by having its arc inclosed in a glass bulb about the size of a small lamp chimney, and usually of similar shape, its central diameter being about twice the average diameter of its ends; it is also made cylindric in shape. It is usually opalescent, but sometimes transparent; and is inclosed in a large, opalescent globe, which may be open, or nearly clcsed if the lamp is intended for outdoor use.

This bulb is nearly air-tight, being closed below by the lower carbon-holder, and above by a close-fitting metal cap through which the upper carbon passes; the only opening being a limited space around this carbon, sufficient to allow its vertical movement without friction. Hence the carbons burn in partly deoxidized air, charged with carbonic dioxide, and consequently at a very slow rate of combustion, their average durability being about

125 hours, or fifteen times as long ~~as~~ that of the open arc carbons.

The regulating apparatus is similar to that in other arc lamps, the upper carbon being moved by a solenoid and clutch. The supply of current is regulated by a resistance coil, usually placed in the upper part of the lamp, but sometimes at some other conveniently accessible point in the circuit. The volume of current is about five amperes, which is about half that employed in open arc lamps, and the E. M. F. is about 80 volts, or nearly twice that in open arc lamps. As a result of this, the inclosed arc is thinner and much longer than the open arc, and gives nearly an equal quantity of light, of clearer quality. Its average length is four to five times the average length of the open arc. Hence the shadows of the carbon points, which interfere seriously with the radiation of the light from the open arc, are scarcely perceptible with this arc; and these points, instead of being cone-shaped, with a crater in the upper point, burn nearly flat, without a crater.

The carbon dust is entirely consumed in this lamp, and the formation and escape of sparks is prevented; hence it is much cleaner for indoor use than the open arc lamp, and involves no increase of fire risk and consequent rate of insurance. The cost of carbons is about one-fifteenth that for the open arc lamp, and the cost of attendance about one-third, daily trimming and renewal of carbons not being required. This amounts to an annual saving of $12 to $15 per lamp, a very material item where a number of lamps are in use, as in a large store, besides the saving of inconvenience and annoyance caused by the lamp trimmer's daily visit. The light is steadier and more uniform in distribution than that of the open arc lamp, and there is no flush and consequent waste of current when the lamp is lighted.

These lamps are intended chiefly for indoor use, but can also be employed for street lighting, and may eventually supersede the open arc lamps for both purposes, when their superior advantages are fully realized. They can be used with either the series or parallel systems of distribution described in chapter X, though chiefly intended for the latter, and on the same circuit with open arc lamps, or incandescent lamps.

CHAPTER VIII.

THE INCANDESCENT LAMP.

WHILE the arc lamp is well adapted for lighting large areas requiring a powerful, diffused light, similar to sunlight, and hence is suitable for outdoor illumination, and for workshops, stores, public buildings, and factories, especially those where colored fabrics are produced, its use in ordinary dwellings, or for a desk light in offices, is impractical, a softer, steadier, and more economical light being required. Various attempts to modify the arc-light by combining it with the incandescent were made in the earlier stages of electric lighting, among which was the sun lamp already described; besides this, Reynier's lamp, invented in 1877, was the most successful. Its construction is briefly as follows: —

REYNIER'S LAMP. — A carbon rod impinges on the circumference of a circular block of carbon which has a rotary motion on its axis. The rod, 12 inches long and $^1/_{12}$ of an inch in diameter, is attached by a horizontal support above to a brass holder which has a free vertical motion in a brass tube placed on a level with the carbon block, and by its weight keeps the rod as it is consumed in contact with the block. The rod is guided in its descent between a small copper roller on one side and a short pointed carbon on the other, the *current* entering the rod through this point at about

$^1/_4$ of an inch above its contact with the carbon block, so that this short portion becomes incandescent, and produces the light. A brake connected with the carbon-holder and block by a horizontal support regulates the descent of the carbon rod; and the rotation of the block, produced by the pressure of the rod as it descends and is consumed, removes the ash and slag. A rod lasts about two hours, and furnishes a light of 114 to 150 candle-power. But the ratio of light produced to electric energy consumed does not exceed $^1/_6$ of that produced by the arc light, and the carbon rod is liable to break and extinguish the lamp.

Various improvements in this lamp have been attempted, such as the substitution of a copper block for the carbon block, also of shorter and thicker rods, less liable to fracture, and of several rods lighted automatically in succession, also of springs or clockwork for gravity in maintaining the contact of the carbons; but none of these semi-incandescent lamps have come into general practical use, though their efficiency in proportion to electric energy consumed was greatly increased above that of the Reynier lamp, so that an efficiency three times as great in proportion to consumption of energy as that of the strictly incandescent lamp, is said to have been attained; and it is possible that such efficiency may ultimately be attained as to bring this system into general use.

EARLY EXPERIMENTS. — The first strictly incandescent lamp was invented in 1841 by Frederick de Molyens of Cheltenham, England, and was constructed on the simple principle of the incandescence produced by the high resistance of a platinum wire to the passage of the electric current. In 1849 Pétrie employed iridium for the same purpose, also alloys of iridium and platinum, and iridium and carbon. In 1845 J. W. Starr of Cincinnati first proposed the use of carbon, and, associated with King, his English agent, produced, through the financial aid of the philanthropist Peabody, an incandescent lamp having twenty-six lights, which attracted the attention and excited the admiration of Faraday. The advantages of carbon over platinum consist in its greater electrical resistance, which is two hundred and fifty times that of platinum; its absolute infusibility, even at very high temperatures; its lower thermal capacity, by which the same amount of heat produces a much higher temperature; and its greater illuminating power at the same temperature as platinum.

In all these early experiments, the battery was the source of electric supply; and the comparatively small current required for the incandescent light as compared with that required for the arc light, was an argument in favor of the former; twelve Bunsen elements being sufficient to produce twelve incandescent lights in one circuit, as demonstrated by DeChangy of Paris, in 1857, while twenty-four to forty elements were required to produce a single arc light. Still, no substantial progress was made with either system till the invention of the dynamo resulted in the practical development of both systems, that of the incandescent following that of the arc.

Among the first to make incandescent lighting a practical success were Sawyer & Man of New York, and Edison. For a long time, Edison experimented with platinum, using fine platinum wire coiled into a spiral, so as to concentrate the heat, and produce incandescence; the same current producing only a red heat when the wire, whether of platinum or other metal, is stretched out. A metal rod, placed inside the coil, was so arranged that when the temperature approached the point where the coil was liable to fusion, the expansion of the rod closed a short circuit, which reduced the current strength, and consequently the temperature: the contraction of the rod produced by the cooling, opened this circuit, and increased incandescence followed.

Failing to obtain satisfactory results from platinum, Edison turned his attention to carbon, the superiority of which as an incandescent illuminant had already been demonstrated; but its rapid consumption, as shown by the Reynier and similar lamps, being unfavorable to its use as compared with the durability of platinum and iridium, the problem was, to secure the superior illumination of the carbon, and reduce or prevent its consumption. As this consumption was due chiefly to oxidation, it was questionable whether the superior illumination were not due to the same cause, and whether, if the carbon were inclosed in a glass globe, from which oxygen was eliminated, the same illumination could be obtained. Another difficulty of equal magnitude was to obtain a sufficiently perfect vacuum, and maintain it in a hermetically sealed globe inclosing the carbon, and at the same time maintain electric connection with the generator through the glass by a metal conductor, subject to expansion and contraction different from that of the glass, by the change of temperature due to the passage of the electric current. Sawyer & Man attempted to solve this problem by filling the globe with nitrogen, thus preventing combustion by eliminating the oxygen, and at the same time maintaining a pressure equal to that of the external atmosphere, so that the leakage by the expansion and contraction of the metallic conductor would be insignificant.

The results obtained by this method, which at one time attracted a great deal of attention, were not sufficiently satisfactory to become practical; and Edison and others gave their preference to the vacuum method, and sought to overcome the difficulties connected with it. The invention of the mercurial air pump, with its subsequent improvements, made it possible to obtain a sufficiently perfect vacuum, and the difficulty of introducing the current into the interior of the globe was overcome by imbedding a fine platinum wire in the glass, connecting the inclosed carbon with the external circuit; the expansion and contraction of the platinum not differing sufficiently from that of the glass, in so fine a wire, as to impair the vacuum.

INCANDESCENT-LIGHT CARBONS. — The next point of greatest importance was to obtain carbons of the proper consistence, tenacity, and durability; and this, as in the case of arc-light carbons, required a long series of delicate and costly experiments with a variety of materials, treated by a variety of different processes.

THE EDISON CARBONS. — The carbons made by Edison under his first patent in 1879, were obtained from brown paper or cardboard, cut into narrow strips in the form of a horse-shoe, which was about $2\,^1/_4$ inches long, and $1^1/_2$ inch in diameter. These were reduced to carbon in an iron mold placed in a muffle, and maintained at a high temperature. They were very fragile and short-lived, and consequently were soon abandoned. In 1880 he patented the process which, with some modifications, he still adheres to. In this process he uses filaments of bamboo, which are taken from the interior, fibrous portion of the plant. The cane, after being cut into sections of the required length, and the hard outer surface removed, is split and shaved down into flat strips, which are then pressed between dies, and fine filaments of the required length and diameter obtained. These are placed in molds made of nickel, in grooves of the required horse-shoe form, and closed so as to exclude the air. The molds are then placed in muffles, and the filaments carbonized at a very high temperature. They are then attached to their platinum wire supports by electro-copper-plating, and introduced into the little lamp globes. The lamp is then attached to a Sprengel airpump, and during the process of exhaustion the filament is alternately heated and cooled by an electric current; the temperature being gradually raised by increase of current strength after each cooling, till a high degree of incandescence is attained. This removes all the occluded gases which remain after the carbonizing, and renders the carbon homogeneous, elastic, and refractory at a high degree of temperature. As this is a far more severe test than any to which the carbon will be subjected in use, all imperfect and defective carbons are destroyed in the process, and only the best survive.

THE LANE-FOX CARBONS.—In the manufacture of the Lane-Fox carbons the raw material is obtained from the bass broom, a species of grass fiber. The hard outer surface is removed by immersion in a solution of hot caustic soda or potash, and subsequent scraping, after which the alkali is removed with boiling water, and the fibers, in lots of about a hundred, bound to blocks of plumbago, shaped so as to give them the horse-shoe form. These blocks, in lots of fifty, are imbedded **in powdered charcoal in graphite** crucibles, placed in a furnace, and subjected for twenty minutes to a white heat. The fibers, after being carbonized in this manner, are gauged and sorted, and all of the same diameter placed together, after which they are suspended separately from spring clips by attachment at the ends, in large globes filled with a hydrocarbon gas obtained from benzole or coal, and subjected to the process termed flashing, first proposed by Sawyer. This process consists in rendering the filaments incandescent, either by the passage of an electric current, or by the heat of a furnace, the latter being the method adopted in the Lane-Fox process. The gas in contact with each filament being decomposed, a layer of hard carbon is deposited, which renders the filament denser, smoother, more homogeneous, more durable, and more uniform in size; the smaller parts becoming hotter than the larger, and thus acquiring a thicker deposit. The increased diameter reduces the resistance, and the process is continued till the resistance required for lamps of a given candle-power, ranging from sixteen to sixty, is obtained.

THE CRUTO CARBONS. — These are made by using as a base a fine platinum wire bent into the horse-shoe form, upon which the carbon is deposited by the flashing process. This is effected by attaching the wires, placed in a long glass vessel, to insulated metallic supports, by which an electric current can be sent through each of them. A current of olefiant **gas,** $C_2 H_4$, circulates through this vessel, the gas being made from alcohol and sulphuric acid, purified by passing through water and lime water, and dried by calcium chloride and sulphuric acid, thus furnishing a gas of pure hydrocarbon. The platinum wires are connected with a shunt circuit so that an electric current passing through them can be graduated to any required strength by a resistance varying from one ohm to two hundred ohms. The wire being heated to incandescence in this manner, the gas is decomposed, and carbon deposited. To insure a uniform deposit, it is necessary to guard against the influence of the earth's magnetism by placing the wires in a plane at right angles to that indicated by the dip of the magnetic needle; and in the latter part of the process the current is reversed. This operation, which requires about two and a half hours, produces a filament remarkably compact and homogeneous, and uniform in cross-section and resistance. Special care is required to maintain uniformity in the successive stages of the process, otherwise the result is a filament of dissimilar superimposed layers of carbon, lacking homogeneity, and practically worthless.

THE SWAN CARBONS. — These carbons are made from cotton twine, prepared by immersion in sulphuric acid diluted with one-third part water, by which they attain a consistence similar to that of parchment; they are then thoroughly washed to remove the acid, reduced to a uniform cross-section by being passed through discs, after which they are wound on rods of carbon or earthen ware, each in the form of a flat spiral having one convolution, and carbonized by being imbedded in powdered charcoal in a crucible raised to a white heat. They are subsequently coated with carbon by the flashing process, and, like the Edison carbons, heated and cooled alternately by the electric current to remove the occluded gases, while inclosed in the globe during its exhaustion. Each filament, when finished, is 5 inches long and .005 of an inch in diameter.

THE WESTON CARBONS. — The raw material used for these carbons is cotton or linen cellulose, which by the action of nitric and sulphuric acids is converted into nitro-cellulose — gun cotton — which is subsequently dissolved in a mixture of alcohol and ether and converted into collodion, and finally has its combustibility reduced by the action of ammonium hydrosulphide or other chemical agent producing a similar effect.

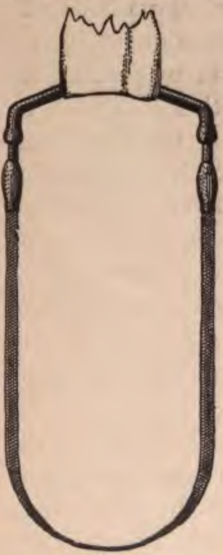
Fig. 82.

This artificial product, which Weston calls "Tamadine," is an amber-colored, amorphous cellulose of great ductility, tenacity, and homogeneousness. It is rolled into thin sheets between steel rollers, and filaments of the sizes required for lamps of different candle-power are cut from the edge of the sheet, bent on shapes into the horse-shoe form, carbonized in the usual manner, and flashed in hydrocarbon gas by the electric process. The carbons when finished are highly elastic, and have a smooth brilliant surface like that of a steel watch-spring.

THE BERNSTEIN CARBONS. — These are made from silk ribbon of the finest texture, woven into a hollow cylinder of the required size, from which sections of the proper length are cut, which are immersed in a thick syrup of cane sugar till saturated, and subsequently in melted paraffine; they are then bent on shapes into the horse-shoe form, placed in graphite molds of the same shape and imbedded in graphite powder, and baked for twenty-four hours. The subsequent flashing process is the same as that for the Lane-Fox carbons. This filament showing the woven structure, is illustrated by Fig. 82, and two of the lamps by Fig. 83, one with a short filament, giving it low resistance, and the other with a long filament, giving it high resistance.

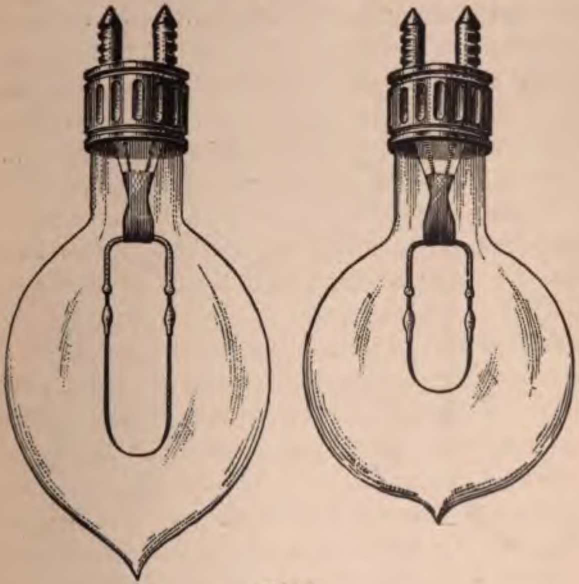

Fig. 83.

These are the only carbons made from an animal substance, and with a hollow structure; and the advantage claimed for this structure is increase of surface, and consequently of radiating capacity with a given degree of resistance.

GENERAL DETAILS OF FILAMENT CONSTRUCTION. — More or less of the details of the various processes of manufacture are trade secrets, as in the case of arc-light carbons; and in some instances the whole process is kept secret, as in the manufacture of the Siemens-Halske and also of the Woodhouse-Rawson carbons.

As the length and diameter of the filament determines to a great extent its electric resistance and illuminating power, it varies according to the E. M. F., current, and kind of carbon employed, so that exact figures can not be given. The Swan filament, as we have seen, is about 5 inches long and .005 of an inch in diameter, and may be taken as representing approximately the average dimensions required for the ordinary 16 candle-power lamp.

The shape of the filament varies, the horse-shoe form being the most common; the Swan filament, adopted also for the Brush lamp, is a flat spiral, as already mentioned, while the Maxim resembles a capital M with the angles rounded off. The Sawyer-Man filament resembles a figure 8. Fig. 84 shows an Edison lamp, and Fig. 85 a Weston, both with horse-shoe filaments; and Fig. 86 a Weston with corrugated filament.

The cross-section of the filament is also a point of considerable importance, determining not only its strength in resisting jars, concussion, and high temperature, but also its illuminating power. As the rectangular form gives greater surface than the circular with the same cross-section, the illumination with a given length is greater, but this can be compensated in the circular form by increasing the length; this increases

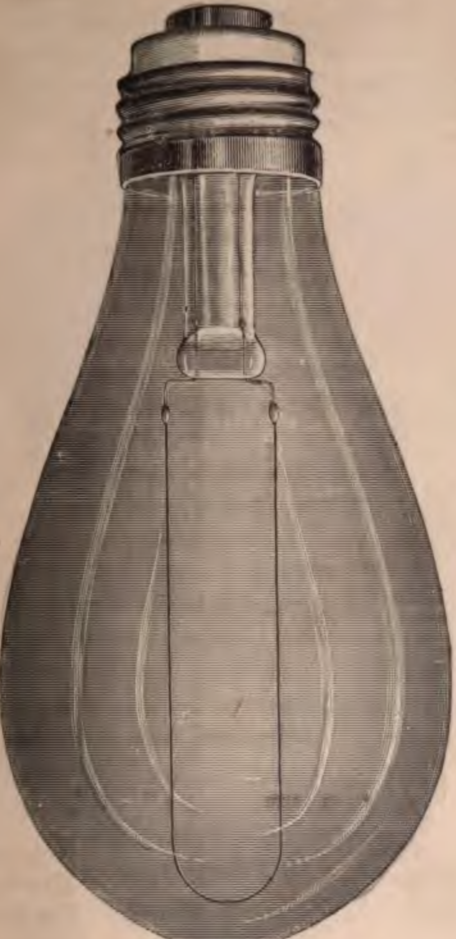

Fig. 84.

the resistance, and consequently the E. M. F. without increase of current. Hence the same illumination can be obtained from the round filament as from the rectangular with greater economy of current. The hollow circular filament, like the Bernstein, gives the maximum of surface with the minimum of substance in cross-section, and hence, as we have seen, the maximum of illumination with the minimum of resistance, and also the maximum of strength in proportion to substance and resistance. Hence, if reduction of resistance in proportion to strength and illumination is

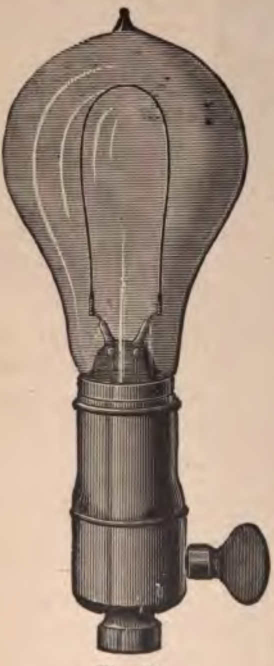

Fig. 85.

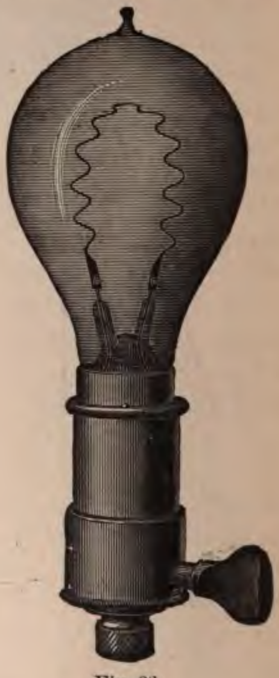

Fig. 86.

desired, either the rectangular or the hollow circular form is preferable; but if increased resistance in proportion to strength and illumination is desired, the solid circular form with increased length is preferable.

The filament is in all cases made largest at the points of attachment, either in the form given previous to carbonizing, or by the subsequent deposition of carbon on the extremities, or their insertion into small perforated carbon cylinders. This is necessary for the purpose of better attachment to the platinum wires, but more especially to reduce the resistance, and hence the strain on the filament at the points where the current enters and leaves, and to increase the strength where liability to fracture is greatest. The attachment of the filament to the platinum wires is accomplished by different methods; that of the Edison, by copper plating, has been already mentioned. The Lane-Fox filaments are cemented into short carbon cylinders, to which also the platinum wires are similarly attached with a cement made of India ink and plumbago. The attachment of the Cruto filaments is effected by their insertion into tubes formed on the ends of the platinum wires, and the subsequent deposition of carbon by the electric process on these junctions. The Weston filament terminates in carbon cylinders, nickel plated, each about $^3/_{16}$ of an inch in length and $^1/_{32}$ of an inch in diameter. around which are wound in spirals the flattened extremities of the platinum wires. This method is also used with the Bernstein filaments, and is attributed to W. Siemens.

The average durability of filaments is estimated at from 600 to 1,000 hours, or from 2½ to 4 months, with an average use of from eight to nine hours a day. While there is no actual consumption such as occurs with arc-light carbons, there is a certain amount of wastage caused by the incandescence and residual air, infinitesimal particles of carbon being given off, in the form of vapor, and being attracted to the glass in consequence of the difference of potential between it and the filament, adhere to the sides of the globes, producing a certain degree of blackening.

It has been observed by Edison that with the direct current this wastage is greater in one half of the filament than in the other. This may be accounted for by comparing the positive and negative halves of the filament to the positive and negative carbons of an arc-light pair; and since the consumption of the positive carbon by its electric conversion into vapor is far in excess of that of the negative, the same process, which we may reasonably assume occurs in the filament on a very limited scale, and proceeds from the same cause, will account for this unequal wastage. It is also well known that the durability of the filament is in proportion to the perfection of the vacuum, the residual air producing slight oxidation during incandescence, which, as in the arc light, would be greatest on the positive side.

But, besides the reduction from wastage, the intense molecular action during incandescence, the alternate heating and cooling, and probably also a certain species of electrolysis, which has been observed in solids as in liquids, reduce the structural tenacity, and are the chief causes which eventually result in the rupture of the filament. This is further shown by the fact that its durability depends largely on the amount of current employed. Increased current produces increased light, but shortens the durability, and it becomes an important economic problem to determine just what amount of current to employ with filaments of a given size and resistance, especially as the rupture of the filament practically terminates the life of the lamp, since filaments cannot, like arc-light carbons, be replaced with new ones in the same lamp, on account of the hermetical sealing and exhaustion of the globe.

Since the wasting of the filament results not only in the conversion of luminous carbon to the black deposit which obstructs the light, but also in increase of resistance by reduction of the filament's cross-section, and consequent decrease of current strength, and hence of illumination at the same potential, the practical value of the lamp usually ceases long before the rupture of the filament, and its further use ceases to be economical.

Lamps of high illuminating power, 100 to 200 candle-power, are constructed either with filaments of proportionally increased cross-section, or with two or more filaments connected in parallel. In the latter construction, the rupture of a filament, though proportionally reducing the light, does not extinguish the lamp, as in the single filament construction. Lamps of 16 to 32 candle-power, for railway service, are also sometimes constructed with two short filaments connected in series, the length of each, and the risk of filament rupture by the jarring of the cars being thus proportionally reduced without reduction of resistance.

Taking three of the leading incandescent systems, as fairly representing the best practical experience in this method of electric lighting, we find that the E. M. F. of the ordinary 16 candle-power lamp ranges from 52 volts to 115, and its current strength from .46 of an ampere to

1.04; the averages being 90.82 volts, and .65 of an ampere, which gives 3.69 watts per candle-power as the average consumption of electric energy. It is found that the flashed filaments are the most durable, and give, on an average, a third more light than those not so treated.

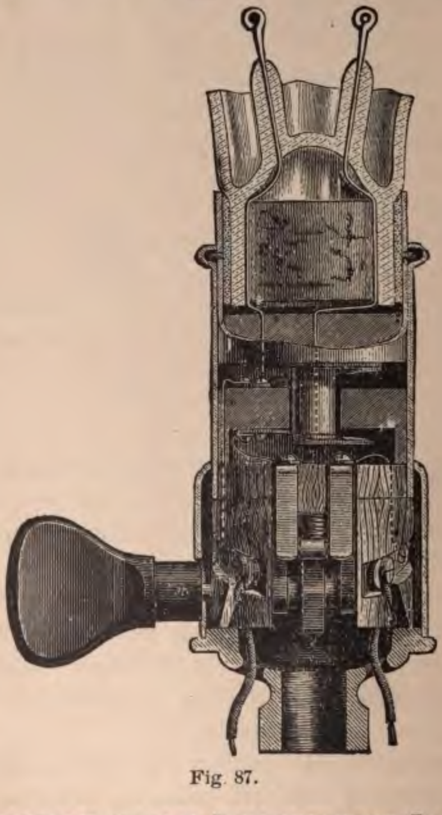

Fig. 87.

CONSTRUCTION OF THE INCANDESCENT LAMP. — As the main features of the incandescent lamps are very *similar*, we may take the latest Weston 16 candle-lamp, Figs. 85 and 86, as a fair sample of their construction. The glass globe, or bulb, is about 3 $^1/_2$ inches long by 2 $^1/_4$ inches in diameter. The filament of the horseshoe form is attached to the platinum wires, as already described; and these pass through two little tubes, as shown in Fig. 87, at the inner closed end of a hollow glass stopper fitted to the neck of the bulb, the glass being fused round them. The neck is wide enough to admit the filament into the bulb without compression; and, after its introduction, the glass is fused around the stopper. A short glass tube projects from the broad end of the bulb, through which the air is exhausted from the interior; after which it is fused, thus sealing the globe hermetically.

The outer end of the tubular stopper is fitted with a wooden insulating plug, which has a central projection about three-eighths of an inch long and one-fourth of an inch in diameter, through which a copper wire, connected with one of the platinum wires, passes, and is attached to a brass screw at its outer extremity; while a copper wire from the other platinum wire connects with a metal washer attached to the broad part of the plug, so that the wires are insulated from each other. A brass collar, connected to the neck outside, fits into a brass tube about two inches long and one inch in diameter, connected to the bracket or chandelier. In this tube are two metal springs, — one of which terminates in a washer, which slips over the projection of the insulating plug, and makes contact with the metal washer on the broad part; while the other makes contact with the screw at the extremity of the projection. These springs are insulated from each other, and connected with the electric circuit, so that the current from one must pass through the filament to reach the other. The circuit is opened and closed by a hinged metal contact piece, operated by an insulating handle; the closing being effected by the pressure of this piece against a pair of springs so connected with the springs already mentioned as to complete the circuit, and the opening by a reverse turn of the handle, which breaks the contact, so that the lamp is lighted or extinguished by a quarter turn of the insulating handle, like a gas jet. A lozenge-shaped piece of metal attached to the handle, as shown, presses down the hinged contact piece to close the circuit, and holds it in position, and a spiral spring lifts it when released, and opens the circuit, the whole apparatus being inclosed in the brass tube mentioned above.

The lamp bulb is held in connection with this tube, and inclosed apparatus, by little projections on the brass collar attached to its neck, which slip into a groove in the lower end of the tube; so that when a filament breaks, it is but the work of a moment to remove the defective bulb and replace it by a new one, the only loss being the bulb and filament, the other apparatus remaining permanent, and the connections with the new bulb taking place by contact, without further manipulation, as soon as it is placed in position.

It will be seen from Figs. 88 and 89, which represent different styles of the latest Swan lamp, that the method of mounting the lamp, and connecting it with the electric circuit, is essentially the same as that of the Weston and Edison, as shown by the description and illustrations already given; the bulb with its inclosed filament, platinum wires and connections, and brass collar, forming one part; and the brass tube to which it is attached,

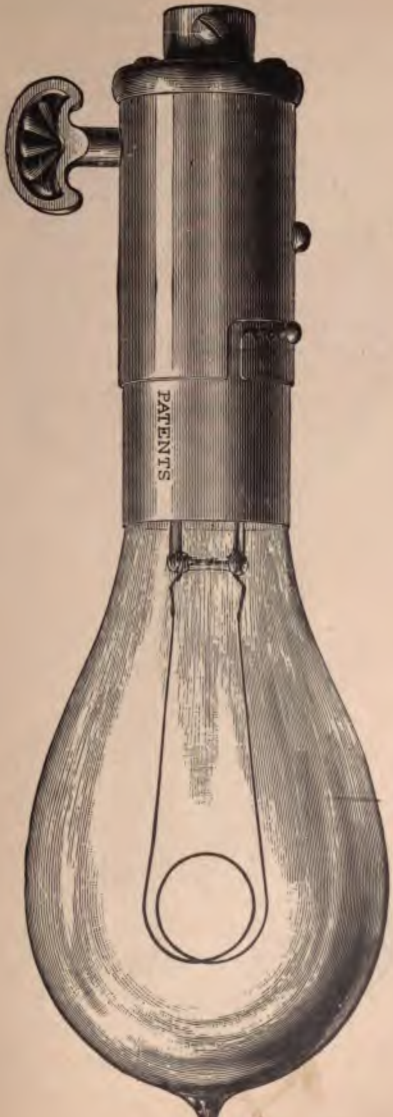

Fig. 88.

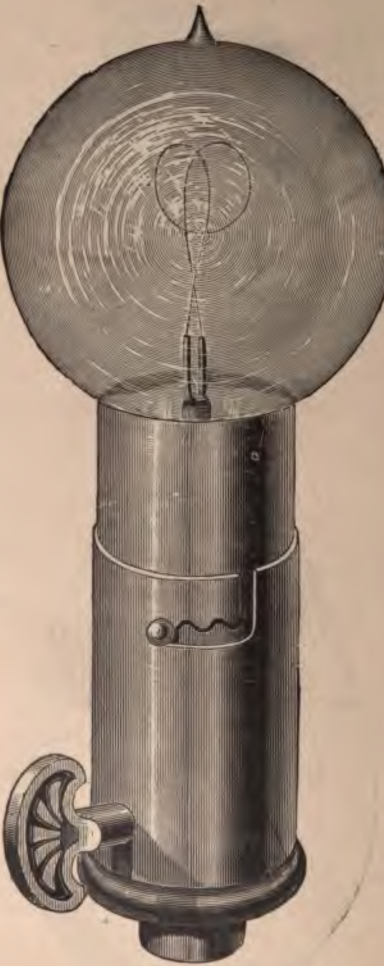

Fig. 89.

as shown, containing the apparatus for opening and closing the circuit by an insulating handle, forming the other part. This apparatus may be varied indefinitely, its construction being a mere matter of mechanical detail.

POSITION OF LAMP.—This lamp does not require a vertical position, like the arc lamp, but may be placed in any position most convenient for the radiation of the light.

VACUUM TUBE LIGHTING.—This method of electric lighting is still in the experimental stage, but promises in the near future to come into practical use, and may eventually supersede incandescent lighting. The light is generated by electric action producing molecular movement in the residual air contained in glass tubes or bulbs, without interior filaments or electrodes, in which a high vacuum has been produced. Three different methods have been devised, by Tesla, Edison, and Moore, respectively.

Tesla uses an ordinary lamp bulb with platinum wires sealed into the neck, and connects it with an induction coil of special construction, operated by an alternating current of very high E. M. F., made disruptive by a toothed wheel interrupter. The light may also be produced by bringing this lamp within the inductive influence of the coil, without direct connection.

Edison uses a tube having platinum wires sealed into its ends and coated inside with a special fluorescent material which does not disintegrate and thus reduce the vacuum. This tube when connected with an induction coil traversed by a rapidly intermittent electric current, is lighted by a fluorescent effect produced on this inner coating by the residual air.

Moore uses a long tube which may be folded into any compact, ornamental form, and coats the ends and a central space externally with metallic paint, on which are wrapped wire terminals. The central terminal is connected with a source of low potential current, and the end terminals with one of high potential current which traverses a primary coil and is made intermittent by a vibrator of special construction.

This vibrator is inclosed, with its contact points, in a glass tube of high vacuum, under which is placed the attracting electromagnet which operates it. Hence the spark which occurs at break, at the contact points of an ordinary vibrator, and is caused by the resistance of the air traversed by a portion of the current, is suppressed by the absence of air in this tube, and the consequent complete intermission of the current; and the electric energy which would be wasted by the spark is applied to the production of the light. There is also a saving of electric energy in the employment of a primary coil in preference to an induction coil; so that the energy required for this lamp does not exceed that employed in the ordinary incandescent lamp.

The end terminals are of equal area and potential, and may be of the same polarity or of opposite polarities, and the central terminal may be of either polarity; difference of polarity being apparently of no importance, while difference of potential between the central and end terminals is of the highest importance.

In each of these lamps, the whole interior glows with a white, phosphorescent light, having but little heat; and the lamps, being without filaments or interior electrodes of any kind, are practically indestructible. So that the long sought desideratum of an indestructible lamp, giving light without heat, seems about to be realized.

CHAPTER IX.

THE STORAGE BATTERY.

ELECTRIC STORAGE. — When water is decomposed by an electric current, and the gases collected in separate receptacles, if the connection with the battery be severed, and the wires leading to the gas tubes brought into contact, a current of electricity will flow through them in the reverse order to that of the original current, the gases at the same time recombining to form water. From which it is evident that the electric energy expended in decomposing the water is stored up in the gases, and recovered when they recombine. Oxygen accumulates at the positive pole, and hydrogen at the negative; and in order to collect the gases, platinum terminals for the wires are required, since the oxygen unites with the terminal, if composed of any of the baser metals, and appears in the combined form of an oxide instead of the separate form of a gas. But experiment proves that electric energy is also stored up in the oxide when so formed, and may be recovered from it.

Observation of these facts by Gautherot and Ritter in the early part of the present century, indicated the possibility of storing electricity so as to obtain a continued current similar to that from the battery, instead of the instantaneous discharge obtainable from the Leyden jar, or the condenser. On this principle Grove, in 1842, constructed a gas battery, using at first oxygen and hydrogen collected in glass tubes with platinum electrodes; but subsequently various other gases, and finally plates covered with peroxides of metals. Numerous other attempts to accomplish this were made from time to time by Wheatstone, Siemens, Kirchoff, and others, but without any practical result till about 1859, when Gaston Planté, a French electrician, began a course of experiments for this purpose, which resulted in the discovery that lead plates could be so prepared, electrically, as to produce the desired result, by allowing the oxygen, as it accumulates at the positive pole, to combine with the lead of a plate provided for that purpose, and form a peroxide (PbO_2), while the hydrogen accumulates on a similar plate at the negative pole. And on this principle he constructed his secondary cell.

PLANTÉ'S SECONDARY CELL. — This cell was originally constructed with two plates of sheet lead, separated by strips of gutta-percha; one sheet being laid over the other with two gutta-percha strips between them, and two more laid on the upper sheet, as shown at *A*, Fig. 90. They were then rolled together and clamped, giving them the compact form shown at *B*, a strip of lead being left attached to one corner of each sheet in cutting, by which connection could be made for charging and discharging. The sheets, rolled together in this manner, were placed in a tall jar of glass or hard-rubber, containing water mixed with ten per cent of sulphuric acid; the jar being fitted with a hard-rubber cover provided with binding screws, to which the connecting strips were attached, and also clamps for holding wires to show the heating effects of the discharge.

The next step was the electrical preparation of the plates, which was accomplished by charging them with a battery of two or more cells, one cell being insufficient to overcome the resistance from polarization. The current was continued till the oxygen evolved at the positive pole ceased to combine with the lead, and was given off as gas. The cell was then disconnected from the battery and discharged, by making connection between its electrodes, and a fresh charge given in reverse order, and continued as before until gas was given off. This process was continued for several months with intervening periods of repose, during which the cell remained charged; and the time of charging was increased from a few minutes on the first day, to several hours subsequently. In like manner the periods of repose were increased from hours to weeks and months.

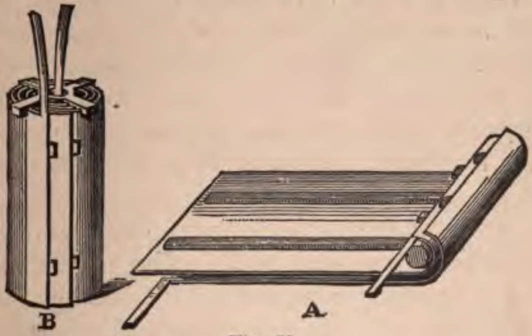

Fig. 90.

CHEMICAL REACTION IN THE PLANTÉ CELL. — To understand the object of this treatment, it is necessary to examine the chemical reactions which take place in connection with the electric action. It will be noticed that three distinct periods are required in this process: the period of charging, of repose and of discharging, during each of which a distinct chemical reaction occurs. During the charging, as already stated, peroxide of lead collects on the plate connected with the positive pole, and hydrogen on the one connected with the negative. But at first only a thin film of the peroxide is formed, and a small amount of hydrogen collected, and the absorption of the gases soon ceases. The plates are then discharged, and during the discharge the peroxide, which is insoluble in sulphuric acid, is reduced to monoxide, PbO, which is immediately reduced to sulphate of lead, $PbSO_4$, by the acid present in the solution; while the oxygen atom, taken from the peroxide, unites with the lead on the opposite plate, forming monoxide, which, in turn, is reduced to sulphate.

The result of the first discharge, then, is a thin film of the sulphate on each plate. The plates are then charged in reverse order, and the sulphate on the plate now connected with the positive pole is reduced by the oxygen to peroxide, while that on the opposite plate is reduced by the hydrogen to spongy lead, which adheres to the plate in a finely divided condition. As each subsequent charge, after discharge and reversal, produces the same result, each coating continues to increase in thickness; and the spongy lead affording increased facility for the formation of the peroxide, the chemical reaction proceeds more rapidly.

But the increased thickness of the peroxide soon interposes a strong resistance to this reaction, hence a period of repose previous to the discharge becomes necessary; and during this period local action, as it is called, takes place. This consists in the reduction of the peroxide to sulphate from the reaction of the supporting lead plate; the metallic lead having a strong affinity for oxygen, the peroxide parts with one atom of its oxygen, which unites with the lead, and the resulting monoxide is immediately reduced to sulphate by the acid.

The chemical reaction of the discharge may now be more fully considered. Its result, as has been shown, is the formation of sulphate of lead on both plates; and this sulphate, lying next to the plates, forms a resistance which impedes local action, which, as shown above, takes place during the period of repose. If the discharge is rapid, there occurs not only a reduction of peroxide to sulphate on the one plate, but also a reduction of a portion of the sulphate on the other plate to peroxide through an excess of electrolytic oxygen; and this reaction tends to reduce the difference of potential, and to produce electric equilibrium.

But during the period of repose, this peroxide, being limited in quantity, and in close contact with the spongy lead, is rapidly reduced to sulphate; while the original peroxide coating on the other plate, from its greater thickness and the resistance of an excess of sulphate, is reduced much more slowly. Hence, there is a partial restoration of the original difference of potential, which accounts for the renewal of electric energy manifest in a partially discharged cell after a period of repose. These various chemical reactions result in an increased thickness of the peroxide deposit with each charge, while an increased thickness of spongy lead remains on the opposite plate after each reversal; and when the process has been continued long enough to produce a sufficient thickness of each coating for a practically serviceable cell, the alternate charging and discharging with reversal is discontinued, and the cell, being ready for use, is always thereafter charged in the same direction.

Each discharge, as shown, produces sulphate on both plates, but the oxygen generated on the plate connected with the positive pole reduces the greater part of the sulphate on that plate to peroxide; while the remaining portion, being in immediate contact with the plate, tends to preserve it from further disintegration. When the cell is put into practical use, these chemical reactions continue, the same as during the forming process, sulphate being reduced to peroxide by each charge, and peroxide to sulphate by each discharge; and the electric energy varies as this reaction, and ceases when the chemical affinities are satisfied.

The electric energy of the secondary cell, then, like that of the primary, is dependent on chemical reaction, the difference being that in the primary cell chemical reaction, with the generation of electricity, takes place spontaneously on the completion of the circuit, and continues indefinitely, for months or years often in well-constructed cells; while in the secondary cell the electric energy must first be supplied from an external source, and the action, both chemical and electrical, is limited and definite, dependent on the amount of electric charge given.

It does not appear that Planté himself fully understood the nature of the chemical reactions which take place, but proceeded on his practical observation of results; and it was not until 1882 that the chemical reactions producing these results were discovered by the English electricians, Gladstone and Tribe, and described substantially as here given.

A cell prepared in this way has a maximum E. M. F. of about 2.54 volts, and a variable resistance of half an ohm or less. When fully charged, it gives for several hours a current of varying constancy, dependent on the external resistance to be overcome, after which the current rapidly declines.

THE PLANTÉ BATTERY. — With a battery of these cells, Planté used a commutator by which they could

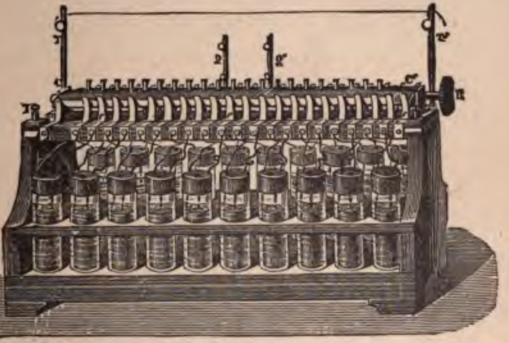

Fig. 91.

instantly be joined either in parallel or in series. Fig. 91 represents such a battery, composed of twenty cells.

The commutator is placed above, and is constructed with a cylinder of hard-rubber, which can be revolved by the milled head *B*. To this cylinder are attached, on opposite sides, two brass strips equal to it in length, against which press 40 brass springs, 20 to each strip, attached to opposite sides of a hard-rubber support, placed underneath the cylinder, as shown. These springs are connected by conductors with the battery electrodes below; all the electrodes intended to be of one kind being connected with the springs on one side, while those intended to be of the opposite kind are connected with the springs on the other side; and thus the cells are joined in parallel.

Between each opposite pair of springs, a brass pin passes through the center of the hard-rubber cylinder, at right angles to the strips: the ends projecting slightly, as shown in the figure. By a quarter revolution of the cylinder the contact of the springs is changed from the strips to the pins, and each opposite pair of springs electrically connected, while insulated from all the others: and thus each positive electrode is connected through the springs and pin with the negative electrode of the adjoining cell; the connections with the springs being so arranged alternately as to produce this result, and thus join the cells in series.

For charging, Planté joined the cells in parallel, and thus obtained a very low resistance, so that two Bunsen cells furnished a current of sufficient strength. But for discharging, he joined them in series, and obtained a maximum current equal to that of thirty large Bunsen cells. But as the battery was not a generator, but an accumulator, it could only return the electricity which it had received less a certain percentage of loss from leakage, which Planté estimated at about ten per cent; and as it was used chiefly for such laboratory experiments as the heating of short wires, the external resistance being very low, the discharge was proportionally rapid, and hence the strength of the current quickly declined, the maximum being maintained for only a few seconds.

Such was the original battery of Planté; an invention of the highest importance when regarded in the light of subsequent development, bearing the same relation, in this respect, to secondary batteries that Volta's does to the primary, but of very limited practical value, and, previous to 1880, scarcely more than a laboratory instrument. But it demonstrated several very important facts: 1. The practicability of constructing a storage battery, which could give, for even a limited time, a continuous and very powerful current, far in excess of that by which the charge was given. 2. That lead was especially well adapted for the electrodes, and water, acidulated with sulphuric acid, for the electrolyte. 3. That peroxide of lead was the best material for the positive plate, and spongy lead for the negative. Its principal defect was the tedious and expensive process of preparing the plates, a defect fatal to the practical use of the battery.

FAURE'S SECONDARY CELL. — About 1880, Camille A. Faure, another French electrician, constructed a cell similar to Planté's, in which he substituted plates prepared by a mechanical process for those prepared by the electric process. His method consisted in coating their surfaces with a paste of red lead (minium, Pb_3O_4) and sulphuric acid, which, when subjected to electric action, was rapidly reduced to peroxide on the one plate, and spongy lead on the other. After this coating was applied, it was covered with paper, and each plate then enveloped in felt, to retain the coating on the surface, and to insulate the plates from each other. They were then rolled together and placed in the acidulated water in the cell, and subjected to electric action with reversal; and in a few days the cell was ready for use.

CHEMICAL REACTION IN THE FAURÉ CELL. — The chemical reaction in this cell, as described by Gladstone and Tribe, is very similar to that in the Planté, but differs in the preliminary stage. The minium on the plate connected with the positive pole is reduced in part to peroxide by the absorption of two atoms of electrolytic oxygen, which, being added to the four oxygen atoms of the minium, make the oxygen atoms double those of the lead; $Pb_3O_4 + O_2 = 3\,PbO_2$. But the sulphuric acid reduces part of the minium on this plate, as well as on the opposite plate, to sulphate; and this sulphate on the opposite plate is, in turn, reduced to spongy lead by the hydrogen, as in the Planté cell. The reduction of minium to sulphate by the acid is as follows: $Pb_3O_4 + 2\,H_2SO_4 = PbO_2 + 2\,PbSO_4 + 2\,H_2O$.

The great advantage, then, of the Faure cell over the Planté, consists in the rapid reduction of minium instead of the slow reduction of metallic lead, thereby greatly reducing the cost. This cell, when subjected to practical tests, was found equal in energy to that of Planté's, and it received the sanction of electricians of the highest standing, while its cheapness and facility of construction commended it at once to popular favor. The invention of the dynamo, too, having greatly reduced the expense and increased the facility of electric generation, the great problem of the supply of electric energy, at economical rates, for general use as an illuminant and a motor, was apparently solved, since the electricity generated by the dynamo could be stored in the battery, to be transported and used wherever required for the propelling of cars or boats, the operation of light machinery, and the illumination of dwellings and offices.

FAULTS OF THE FAURE CELL. — But the new cell soon developed serious faults, which had to be overcome before these ends could be realized. The coating could not be made to adhere to the surface with proper uniformity, but sloughed off partially, and collected in a mass at the bottom of the felt envelope. The space between the plates being entirely filled by the felt, the free circulation of the electrolyte necessary to the proper action of the cell was impossible; and the felt, becoming corroded and partially removed in spots by the acid, soon ceased to act as an insulator; short-circuiting ensued, and the cell became worthless. But the rapid preparation of the plates by mechanical process was a very important step in advance of the slow electric process of Planté; and while the disappointment at the failure of the battery was as great as the enthusiasm with which its first appearance was hailed, electricians, confident of ultimate success, still worked patiently to overcome the faults which had been developed.

THE IMPROVED FAURE SECONDARY CELL. — The various improvements of Swan, Sellon, Volckmar, Shaw, and others, from 1880 to 1886, resulted in producing the improved cell shown in Fig. 92. It is made of different sizes, and with a variable number of plates, according to the purpose for which it is intended, the style here shown being the 23-plate stationary cell, having 11 positive plates and 12 negatives,—those plates being known as positive which are connected with the positive pole in charging, and from which the external current flows in discharging, and the others being known as negative. Each set is attached to a lead cross-bar above and at the center, by which the plates are held at a fixed distance apart; the two sets interlocking, so that positive and negative plates alternate and are insulated from each other by two rows of hard-rubber forks. Each plate is ⅛ of an inch thick, and the space between adjacent, positive and negative plates, $\frac{5}{32}$ of an inch wide; and the two outside, negative surfaces being inactive, each set has 22 interior, active surfaces.

A thick plate of glass, under the central cross-bar and plate connections on each side, supports the plates, so as to leave a space underneath for the free circulation of the fluid; each set being supported, on its opposite side, by plate projections which rest on an insulating hard-rubber strip above each cross-bar as shown; two stout rubber bands holding these supporting plates and the lower parts of the lead plates in position. A lead bar, projecting from the cross-bar of each set, can be bent into any convenient position for making connection with adjoining cells.

These plates are immersed in water acidulated with 36 per cent sulphuric acid, contained in a glass jar 10½ inches long, 8½ inches wide, and 9⅞ inches high; the entire weight of jar and contents being 50 lbs.

The glass jar has the advantage of allowing inspection of the interior without disturbing the contents, by which the condition of the plates may be observed, and short-circuiting from the buckling of plates or the lodging of loose paste plugs between them remedied; but its comparative frailty and weight are objections to its use for the portable cells required on cars and elsewhere. Hence a portable cell of the same capacity and number of plates is constructed with a covered, hard-rubber jar, made shorter below than above so as to furnish supporting ledges for the plates at the opposite ends, which take the place of the glass supporting plates employed in the stationary cell. The weight of this cell is 40 lbs., its height about the same as that of the stationary cell, and its other dimensions about one fourth less.

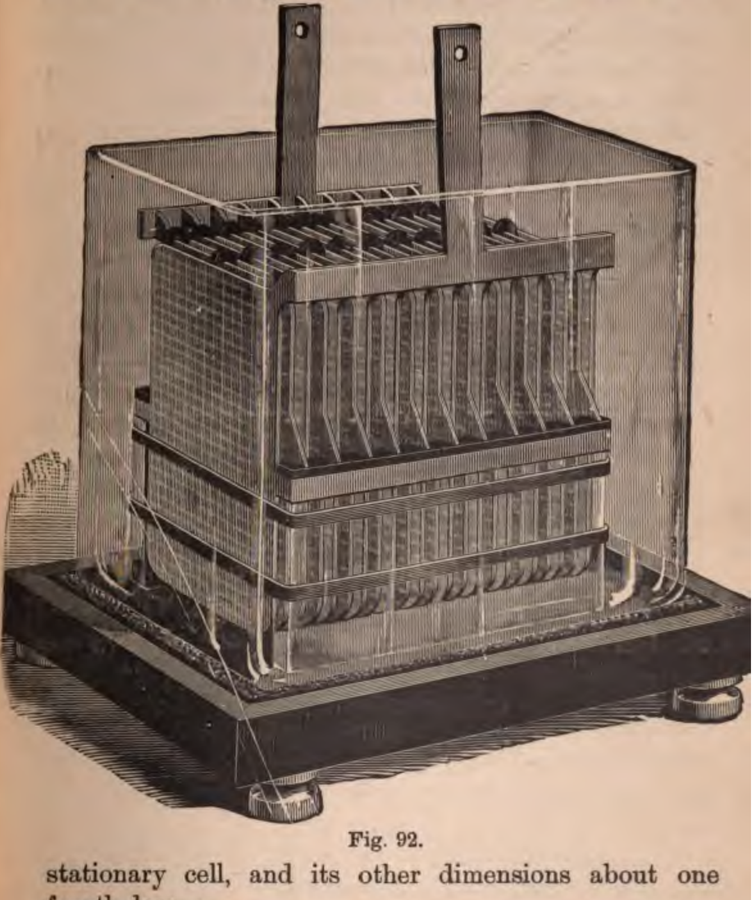

Fig. 92.

The 15-plate stationary cell has 7 positive plates, each $\frac{6}{32}$ of an inch thick, and 8 negatives, each $\frac{5}{32}$ of an inch thick, contained in a glass jar 10¾ inches long, 12¼ inches wide, and 13¾ inches high; the entire weight being 130 lbs., and the storage capacity 300 ampere-hours, double that of the 23-plate cell. The supporting plates are of hard-rubber, with openings for inspection, and are each held in position by two metal rods which pass through loops in the positives at one end and in the negatives at the other, binding the plates of each set together below and furnishing electric connection between them. The plates are made of lead, cast in the form of grids, with square openings to hold the paste, as shown at *A* in Fig. 93, this form being the invention of Swan. Each opening is ⅜ of an inch square at the surfaces, but smaller at the center, the walls being thicker, sloping inward from each surface, as illustrated by the cross-section shown at *B*, an improvement made by Sellon to prevent the paste from dropping out. These openings are filled with the paste of lead oxide and sulphuric acid; minium, Pb_3O_4, being used for the positive plates, and litharge, PbO, for the negatives, each plug being held in its place by the peculiar form given to it by the opening.

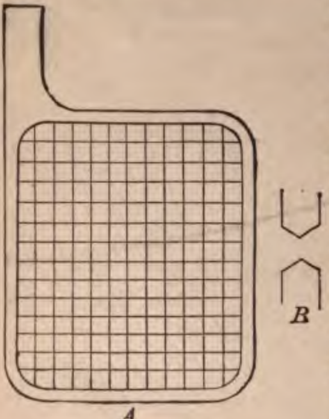

Fig. 93.

ELECTRIC FORMATION OF THE PLATES. — In the electric formation of the plates at the factory, each set is charged separately, a set of temporary plates, or dummies, of each kind being used with each permanent set. As the formation of the negatives requires a much longer time than that of the positives, litharge is preferred for them, being far more rapidly reduced than minium, which is used for the positives. But this difference of material compensates only partially for the difference in time; the negatives requiring six days for the reduction of the litharge to spongy lead, while the positives require only twenty-four hours for the reduction of the minium to peroxide. But the use of the dummies prevents any inconvenience which might arise from this source, and renders the old process of reversal unnecessary. After the plates have been formed in this way, they are partially discharged before shipment, and require to be properly charged when the cells are completed and ready for use.

ELECTRO-MOTIVE FORCE, RESISTANCE, AND CURRENT OF CELL. — The average E. M. F. of the cell is about 2 volts, its internal resistance from .001 to .005 of an ohm, and its working capacity 300 ampere-hours. The current varies with the external resistance, and the rate of discharge can be regulated by this resistance. A medium rate gives the most satisfactory results, and is found to be the most economical. Hence, while a current of 300 amperes can be obtained and the cell discharged in an hour, such a rate is wasteful, and would soon injure the plates; while with a 30-ampere current the cell will do efficient work for 10 hours, without waste or injurious results.

It has been shown that the electric energy obtained by the discharge depends on the coincident chemical reactions, and that these reactions require time for their normal development; hence if the discharge is too rapid there will be abnormal chemical reaction with corresponding waste and injury. For the same reason, a medium rate of charging which allows sufficient time for the complete chemical reduction of the gases is the most economical; while with too rapid a rate, a portion of the gas escapes and is lost. The same result follows from overcharging, though in either case there is no injury to the plates, since there is no excess of chemical reaction as in discharging. As a result of the charging, a residual amount of gas adheres to the plates, oxygen on the positives, and hydrogen on the negatives, which does not enter into chemical combination; this increases the initial E. M. F. of the discharge to 2.25 volts; but as this gas is soon reduced, the E. M. F. falls rapidly, so that at the end of the first half hour it is about 2.04 volts, after which it remains nearly constant for several hours, gradually declining to two volts or less. When the cell is nearly discharged, the decline becomes very rapid, and if the discharge is continued when this stage is reached, permanent injury to the plates is the result; hence the discharge should be stopped when the E. M. F. falls much below two volts.

CAUSE OF BUCKLING. — Buckling is a result of the formation of sulphate in discharging, producing unequal expansion. If it were possible to obtain perfect uniformity in the material of the plates and in the solution, so that the expansion in discharging, and the contraction which follows in charging, should be uniform, buckling could not occur. But, like every other species of warping, it is a result of want of uniformity, either in the material, or in the action to which it is subjected, or in both. The acid, from gravitation, becomes denser in the lower part of the cell, and this affects both the chemical reaction and electric conductivity, both of which are greatest when the acid is most dense; and observation on buckled plates shows a curving from top to bottom, steadily increasing downward. But buckling does not interfere with the action of the cell until it has proceeded far enough to produce short-circuiting, by bringing plates into contact, or displacing plugs of paste.

The pressure of the hard-rubber forks tends to prevent buckling and to maintain evenness of surface, keeping all the plates everywhere at equal distances apart; while the rubber bands, by their elasticity, keep the pressure uniform, so that if buckling occurs, it is likely to affect all the plates equally, in which case short-circuiting cannot occur. The rubber bands and forks have also the very important qualities of being good insulators, and practically indestructible in the acid.

VARIABLE RESISTANCE OF ELECTROLYTE. — The expansion of the plates while discharging is the result of the absorption of sulphuric acid to form the sulphate, and the acid absorbed in this way during the discharge is restored during the charging; from which it is evident that the conductivity of the electrolyte is subject to continual variation; steadily increasing during the charging until the full proportion of acid is restored, and declining during the discharge as the acid is absorbed; consequently the internal resistance of the cell varies inversely in the same ratio, and hence the necessity of the large percentage of acid used, that the resistance during the discharge may not become so great as to lessen the practical efficiency of the cell; as a smaller percentage would be liable to entire absorption before the termination of the discharge, leaving only water, which has a very high resistance as compared with that of dilute acid.

Too large a percentage of acid is also detrimental by producing an excess of sulphate, and consequent buckling of the plates during the discharge; so that the proper proportion to be used is of great practical importance, and the 36 per cent. already mentioned, seems to give the best practical results.

THE AMERICAN CELL.—This cell is constructed with plates of pure rolled lead, each $\frac{7}{16}$ of an inch thick, with grooves cut on both surfaces, as shown in Fig. 94, in perspective at A, and in cross section at B. Hard rubber separators, made as shown at C, insulate the plates from each other when assembled in the cell. The active material is contained in the grooves, and formed from the plate itself by electrochemical action, as in the Planté cell, but by a much shorter process, the nature of which is a business secret, but which requires only two days for the complete formation of lead peroxide in the positives and *spongy* lead in the negatives. This material, being

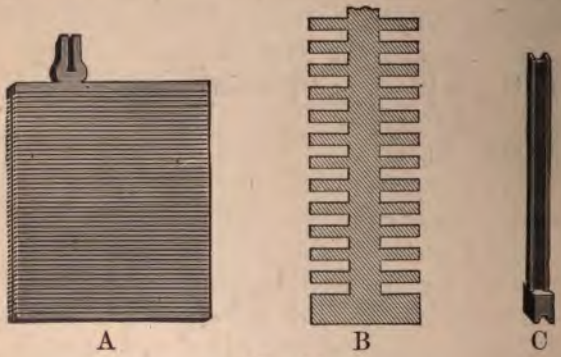

Fig. 94.

formed from the pure lead of the plate itself, is perfectly homogeneous throughout, and hence is claimed to be more durable and efficient than when formed from applied lead oxides, liable to differences in quality, as in the Faure plates.

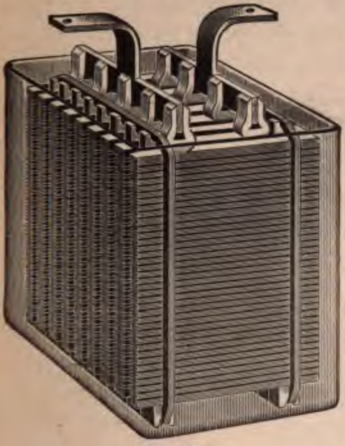

Fig. 95.

The plates are assembled in the cell, as shown in Fig. 95, positives and negatives alternating, are bound together with stout rubber bands, and electrically connected by transverse lead bars soldered to clamps on the upper edges, and are immersed in a fluid composed of one part sulphuric acid and five parts water.

The cells complete, without fluid, range in weight from 4 pounds to 120, and in external size, from 34 cubic inches to 2000.

THE CHLORIDE ACCUMULATOR.—The plates of this cell are about $\frac{5}{16}$ of an inch thick, and are constructed with small disks, which are fixed in a mold, and melted lead, alloyed with a small percentage of antimony, forced in around them under strong pneumatic pressure, producing a dense structure free from air holes. The disks for the positive plates are made of lead tape, grooved crosswise on one surface, and formed into flat rolls; the grooves producing holes, or pores, through the disks which are softened and rendered more porous by immersion for a few minutes in nitric acid. The edge is concave, so that the disk is larger at the surface than at the center, *and is therefore* held in the plate like a rivet.

The disks for the negative plates are made of a mixture of lead and zinc chlorides, fused together and cast in molds; and are convex at the edges, and hence smaller at the surface, than at the center, and therefore held in position by the inclosing surfaces of the plate.

The negative plates are electrochemically formed by being placed, for two days, in a solution of zinc chloride, in contact alternately with zinc plates. The combination acting as a primary battery, removes the chlorides from the disks, leaving in them only highly porous, pure lead.

The plates of both kinds are then assembled in a tank containing dilute sulphuric acid, each kind being connected together outside the tank by a conductor, alternating with the other kind in position, and insulated from them; and are subjected for some days to the action of a dynamo current, flowing constantly from the positive to the negative set, by which lead peroxide is formed from the lead tape composing the disks of the positive plates, the spongy lead composing the disks of the negative plates remaining unchanged.

They are then placed in the cells, the positives being insulated from the negatives, which alternate with them, by separators of hard rubber which have circular contact knobs on both surfaces and inclose each positive plate at two points; and dilute sulphuric acid being added, the cells are ready for use.

DURABILITY OF STORAGE CELLS.—Manufacturers usually guarantee for the positive plates a durability of one year, in constant practical use, with a normal current. The negatives are far from durable, not being subject to oxidation; and unless injured by buckling, last for an indefinitely long period.

CHAPTER X.

ELECTRIC DISTRIBUTION.

WE have seen, in the preceding chapters, how electricity may be generated, measured, accumulated, and made to produce light. It now remains to be shown how it may be distributed from the generator to the lamps.

In small installations — as in the lighting of a single store, factory, or office building — distribution is comparatively easy: but, with increase of area and of the number of lamps, the difficulties increase; so that distribution over a large area in a town or city, from a central station, by means of conductors placed on poles or in underground conduits, supplying current to numerous consumers under varying conditions, accurately measuring the amount of current consumed by each, guarding against wastage of current, and against danger to life and property from its effects, is a problem in electrical engineering of the greatest intricacy and magnitude.

ARC-LIGHT DISTRIBUTION. — The methods of distribution for the arc light and the incandescent light are essentially different. As each arc lamp consumes a large amount of current, while the amount consumed by each incandescent lamp is comparatively small, the number of lamps fed by a given supply of current must vary in like proportion, and the means of distribution must be such as to furnish the proper amount to each without wastage. A ten-ampere current required by an arc lamp, for example, would supply twenty incandescent lamps of ½ an ampere each. Hence, it is found most practical and economical to adopt the series system of distribution in arc lighting, and the parallel in incandescent lighting. But arc lamps, especially for indoor lighting, are often installed with incandescent lamps on a parallel circuit; and as the E. M. F. required by them is much less than that required by the incandescent lamps, while the volume of current is much greater, the E. M. F. is reduced by passing the current through a resistance coil, at each arc lamp, and the volume of current increased by the comparative low resistance of the arc lamp. Incandescent lamps of large candle-power may be installed with arc lamps on a series circuit, but the difference between the two kinds, in E. M. F. and current volume, makes such installation undesirable.

In both systems the E. M. F. or voltage of the dynamo, and the resistance of the circuit, are the factors which govern the supply of current, and the chief fundamental principles on which every installation is based, copper being always used for the conductors.

SERIES INSTALLATION. — Fig. 96 gives a good general idea of an arc light installation; *L*, *L*, *L*, representing the lamps in series, and *D* the dynamo, series wound, with its + and — poles, as marked, from which the direction of the current can be ascertained. The position of the wires is a mere matter of convenience. They may be led through a building in any direction, — through or along walls, ceilings, or floors, — provided that proper insulation is maintained, and proper precaution against dangerous proximity to inflammable substances or to the occupants. In such an installation the full current, leaving the dynamo at + and returning to it at —, passes through every lamp in the series. This current is maintained at a certain constant strength required by the construction of each particular style of lamp, and determined by the E. M. F. of the dynamo, and the full resistance of the entire circuit, including the dynamo, the lamps, and the conducting wires. The strength of current required varies greatly, ranging from ten to twenty amperes for series installations in the various leading arc light systems. Assuming a 15-ampere current to be required by the ten lamps shown in Fig. 96, and that each lamp has a resistance of 3 ohms, the dynamo a resistance of 5 ohms, and a mile of No. 6 B. & S. wire, required for the circuit, a resistance of 2 ohms, then $(10 \times 3) + 5 + 2 = 37$ ohms the entire resistance, and 37 R × 15 C = 555 E. Hence, such an installation would require a 555-volt dynamo, each of the ten lamps requiring 55.5 volts.

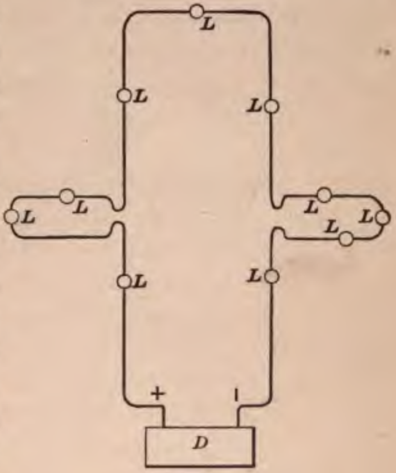

Fig. 96.

Hefner von Alteneck's Regulator. — Each lamp in such a circuit is provided with a shunt similar to that used with the Brush lamp, as described on pages 180–183, by which constancy of current is maintained under change of resistance. This construction, which varies in different systems, was first introduced by Hefner von Alteneck, as mentioned on page 177, and will be readily understood from Fig. 97. The line L divides at i; the upper branch, composed of fine wire, being the shunt, and including the fine wire coil R, reunites with the main line L_1 at the lower carbon holder b, thus passing round the lamp; the lower branch, composed of coarse wire, and including the coarse wire coil R_1, is connected with the lever $c\ c_1$, near its fulcrum d, the arm c_1 connecting with the carbon holder a, and c with the iron rod $s\ s$, the weight of the rod counterbalancing that of the carbon and holder. This branch is thus connected directly with the lamp, reuniting with the main line at b. When the carbons k, k_1, are in contact, and a current passes, it divides at i in proportion to the respective resistance of each branch; the stronger current going through the coil R, and carbons k, k_1, to the line L_1; rod $s\ s$ is drawn down by the greater attraction produced by the stronger current through the low resistance coil R_1, the upper carbon K is lifted, and the arc lighted.

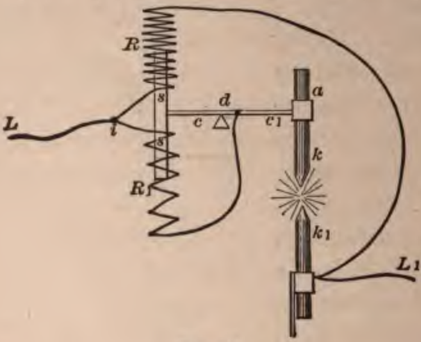

Fig. 97.

The lighting of the arc increases the resistance of the lower branch, and in like proportion the potential difference, or E. M. F., between L and L_1; and the strength of the current in R being increased by this increase of E. M. F. in the same ratio as that of R_1 is diminished by the increased resistance, the descent of the rod *s s* is checked by the opposing attraction of the coil R. The arc is thus maintained at its normal length by the opposing attractions of the two coils; any tendency to variation of length in the arc tending to produce corresponding variation of the relative current strength in the opposing coils.

It is evident that by varying the amount of wire in either coil, or changing its position with reference to the depth to which the rod *s s* penetrates, any required adjustment of relative strength in attracting the rod may be obtained.

The term differential is used to designate lamps constructed in this manner. Without some such construction, it would evidently be impractical to place lamps in series, as any variation of current strength in one lamp would affect every lamp in the series, producing continual fluctuation of the light, which would increase with the number of lamps; and if one lamp were extinguished, the interruption of the current would extinguish all the others; while the extinguishing of a differential lamp diverts the entire current through an automatic cut-out, similar to that of the Brush lamp, already described, by which an extinguished lamp is entirely eliminated from the circuit, and the full current permitted to flow to the other lamps; the constancy of the current at a given strength being maintained by the various devices already described in connection with dynamos.

This ideal representation of an arc-light installation is intended to embrace the leading principles which govern every such installation, while in their practical application they are modified according to the requirements of each particular system. The number of lamps in one circuit fed by a single dynamo varies from one to fifty, or more; and the resistance, electro-motive force, current, candle-power, and methods of regulation, are numerous, and differ widely in the various systems.

The dynamo is almost exclusively the direct current, series wound machine, the alternate current dynamo being seldom used now for arc lighting.

In distribution to an extended area from a central station, in both arc and incandescent lighting, large conductors are used for the main leads, composed often of copper wires twisted together as a cable, to give the required flexibility combined with size. In large cities the mains, properly insulated, are usually required to be placed in underground conduits of lead or iron pipe, the iron being usually laid in the earth under the pavement, while the lead are inclosed in sub-ways, preferably of a composite insulating material, into which they can be drawn without disturbing the pavement. Branch circuits from the main line, and connected with it in series, extend into stores, office buildings, and factories; and the consumption of current is estimated by the number of hours light is required, and the size and number of lamps; a method which becomes the more practical since the lamps require daily attention by an expert, for renewal of carbons.

Numerous independent main circuits extend from large central stations, fed by powerful dynamos; the *number* of dynamos running simultaneously varying according to the amount of light required at different periods during each twenty-four hours, thirty to forty being often in operation at the same time in one room.

INCANDESCENT LIGHT DISTRIBUTION. — Incandescent lighting, as already stated, requires the parallel system of distribution.

The difference between this and the series system will be understood from Fig. 98. Between two main conductors extending from the dynamo, are placed, in parallel, several short lines connecting with the lamps, the current being thus divided among the lamps in proportion to their number and resistance, while in the series system the entire current passes through every lamp. This method is common to both the direct and alternating current systems, which in other respects are so radically different, especially in their methods of distribution, that it is important to consider each separately.

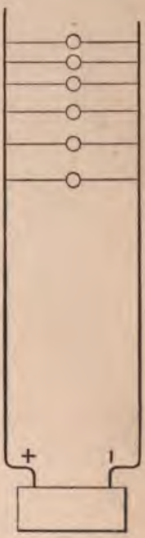

Fig. 98.

THE DIRECT CURRENT SYSTEM. — The dynamo in this system has usually an effective E. M. F. of about 100 volts, after allowing a small percentage for loss in distribution; it is either shunt wound or compound wound, so that the current which goes to the lamp circuit is either wholly or partially independent of that which passes through the field-magnet coils, and hence the resistance of this dynamo in the circuit is far less than that of the series wound machine, in which the entire current passes through those coils.

As the main conductors are required to carry a very large current, they are proportionally large; the cross-section varying in proportion to variation of length, and number of lamps to be supplied, in order to equalize the resistance, and maintain constancy of current; it may be less than half a square inch, or exceed twelve square inches. As a fair illustration of the required size, it may be stated that the cross-section of a cable required to carry a current sufficient to feed 5,000 16 candle-power lamps, at a mean distance of 4,000 feet from the dynamo, would be about 12.57 square inches. But as the current divides at each short parallel line, the size of the main conductors is proportionately reduced as they extend; while these short lines on which the lamps are placed, require only single wires of about No. 14 or 16 gauge.

The resistance of the leading mains is, of course, very low; and the fall of potential between the dynamo and the lamps, due chiefly to this resistance, varies usually from 2 $^1/_2$ to 10 per cent. To reduce this loss so as to raise the potential at the lamps to a certain given percentage, without change in the efficiency of the dynamo, the cross-section of the mains must be increased in proportion to the square of the increase required in percentage; and as this must evidently make a great difference in the amount of copper required, this percentage becomes a very important factor, requiring careful calculation in every installation.

The resistance of the lamp, on account of the fineness and length of the carbon filament, is far in excess of that of the arc lamp; and the filament when cold has nearly double the resistance of the heated filament through which a full current is passing; hence the cold resistance of the circuit, when the current is first turned on, is far in excess of the subsequent hot resistance.

PARALLEL INSTALLATION. — From these data we can form an ideal estimate of an installation arranged as in Fig. 98. If we suppose all the short parallel lines removed except the upper one with its lamp, or, what is practically the same, all the lamps except the upper one extinguished, the arrangement would not differ materially from that of an arc-light circuit having a single lamp; the entire current passing through this lamp, and its strength being determined by the effective E. M. F. of the dynamo, assumed to be 100 volts, divided by the entire resistance, including as before that of the dynamo, the conductors, and the lamp. Estimating the resistance of the dynamo and conductors at 1 ohm, and the hot resistance of the 16 candle-power filament at 199 ohms, we have an entire resistance of 200 ohms, and $\frac{100E}{200R} = \frac{1}{2}$ an ampere, the current strength. But if two lamps be lighted, we furnish two paths of equal resistance, instead of one, between the mains, and reduce the filament resistance in the same ratio; $1R + \frac{199R}{2} = \frac{201R}{2} = 100\frac{1}{2}$ ohms. And since the fraction in this case is practically insignificant, it may be neglected, and we have $\frac{100E}{100R} = 1$ ampere, the entire current strength, which, being equally divided between the two lamps, gives each $\frac{1}{2}$ an ampere as before.

For any small number of lamps the resistance varies inversely and the entire current directly as the number lighted, and the current per lamp remains practically constant, as shown, being equally divided among the entire number lighted. But as the resistance of the dynamo and circuit remains constant while that of the filaments varies, it is evident that in the lighting of any considerable number of lamps the fraction, neglected above, would make a sensible difference in the ratio of resistance to E. M. F. Suppose that 100 were lighted, then the entire filament resistance would be $\frac{199R}{100} = 1.99R$, and, adding in the 1 ohm constant resistance, we have 2.99 ohms as the entire resistance; hence $\frac{100E}{2.99R} = 33\frac{44}{100}C$, which, divided among the 100 lamps, gives about $\frac{1}{3}$ of an ampere per lamp, instead of $\frac{1}{2}$ an ampere, with only one or two lighted.

There is also a certain amount of current wastage, making an entire current variation of 15% to 20%, which must be provided for in order to maintain constancy of current and illumination. This, in the direct current system, is done by the introduction of resistance coils into the circuit, by which the current can be varied by variation of the resistance, and in the alternating current system by a direct variation of current in the converter. Hence when the indicator at the station shows a variation of current below or above the normal, by the lighting or extinguishing of any considerable number of lamps, the attendant makes the necessary correction by moving a switch either in the resistance box or converter, according to the system of lighting employed.

The necessity for the greatly increased size of the mains, as compared with those used for arc lighting, becomes apparent when we compare the requirements of a 200-ampere current with those of a 10-ampere current.

MULTIPLE SERIES INSTALLATION. — The parallel system of distribution, shown in its simplest form in Fig. 98, is variously modified for different purposes. While it is generally preferable to place each lamp on its own separate branch between the mains, so that it can be lighted or extinguished without interfering with the other lamps, it is sometimes desirable to combine the series with the parallel system, producing what is termed the multiple series method; that is, several series in parallel with each other. This method is illustrated in Fig. 99, which shows three series in parallel. Such a method is sometimes convenient for lighting a large room, as a public hall, store, or church, where a large number of lamps are required at the same time. By the method shown in Fig. 99, several such rooms in a large building or in different buildings can be lighted by the same dynamo.

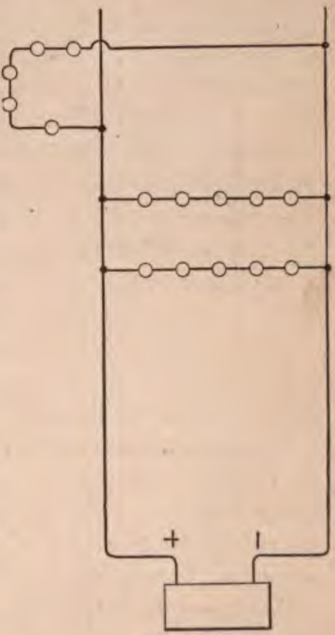

Fig. 99.

Large dynamos can be advantageously employed for such installations; for the E. M. F. of the dynamo must correspond to the requirements of the lamps, and as the entire E. M. F. or electric pressure goes to every branch of the circuit, it is divided among the several lamps on each branch in proportion to the number in each series, and the required voltage of each lamp. If the dynamo in Fig. 99 were a 500-volt machine, and 100-volt lamps were used, five lamps would be required in each series as shown, or ten 50-volt lamps; or series of five 100-volt lamps, and ten 50-volt lamps could be placed in the same installation.

To prevent the extinguishing of all the lamps in a series, which must result from the extinguishing of any single one, an automatic cut-out is required for each lamp, as in arc lighting; and, to maintain constancy of resistance, an artificial resistance, equivalent to that of the extinguished lamp, must be switched in as the lamp is cut out, or else another lamp of equal resistance automatically lighted.

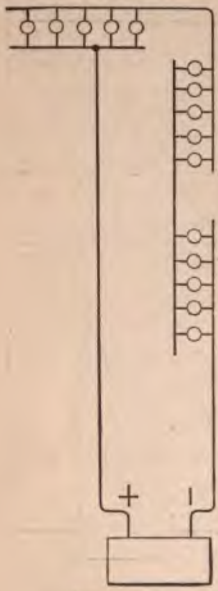

Fig. 100.

SERIES MULTIPLE INSTALLATION. — Instead of serial groups placed in parallel, as just shown, parallel groups may be placed in series, as shown in Fig. 100, constituting what is known as the series multiple method. While in the multiple series method the entire E. M. F. goes to each group, and is divided among its lamps, as has been shown, the entire current in the series multiple method goes to each group, and is divided among its lamps, in proportion to their number. A 2½-ampere *current* in the mains would therefore furnish a current of ½ an ampere to each of the five lamps in each group in Fig. 100.

Such an installation is practically on the same basis as an arc-light series, the groups of incandescent lamps taking the place of the single arc lamps, and the E. M. F. of the dynamo, and general resistance of the circuit varying according to the number and resistance of the groups, so as to keep the current constant, while specific regulation is required in each group, the E. M. F., resistance and current being here dependent on the parallel arrangement, and required to be the same for each lamp; and since the extinguishing of one or more lamps in a group would disturb this equilibrium, abnormally increasing the E. M. F. of the remaining lamps, a regulator is provided, as in the Brush system, by which extra lamps are automatically lighted to take the place of those extinguished, or the whole group cut out, as on an arc-light series, in case the whole, or a large proportion, of the lamps are extinguished, so that the current flowing to the other groups in the series shall not be interrupted or diminished.

COMBINED ARC AND INCANDESCENT INSTALLATION. — Arc lamps are sometimes placed in series with the groups of incandescent lamps, in which case the current strength of each group and that of each arc lamp must be the same. If arc lamps requiring a ten-ampere current are used, each incandescent group must absorb this current; hence, it may consist of ten one-ampere lamps, twenty half-ampere lamps, or any other number which multiplied by the current per lamp gives ten amperes.

Distributers are, however, sometimes employed in which so much of the current as may be required for a group is shunted through it, and a resistance coil provided for each lamp, so that when a lamp is extinguished a coil of equal resistance is automatically substituted for it, and constancy of resistance maintained.

It is, however, extremely difficult, in such an installation, to maintain proper equilibrium between the arc and incandescent lamps, so as to produce satisfactory results.

Instead of groups of incandescent lamps in parallel, single incandescent lamps of large candle-power, requiring a current of corresponding strength, may be placed in series with arc lamps requiring a current of the same strength.

THE EDISON THREE-WIRE SYSTEM. — The large amount of copper necessary for the leading mains of an incandescent light installation to carry the current required for any considerable number of lamps distributed over an extended area, and remote from the central station, has proved financially a serious obstacle to progress in this method of electric lighting. Among the methods devised to reduce this amount of copper without impairing the efficiency of the system, the Edison three-wire system stands prominent. In order to understand its advantages, we must compare it with the two-wire system. Fig. 101, letter *A*, represents two dynamos, each having its two leading mains of the usual size, carrying a current to lamps in parallel, and extending in the same general direction, the efficient E. M. F. of each, at the lamps, being estimated at 110 volts, after allowing a fall of ten per cent in the mains and connections. If now these dynamos be joined in series, as represented at *B*, we can suppress two of the mains, and join each two lamps in series also. We would have, then, at *A* a practical E. M. F. of 110 volts to each lamp, and at *B*, of 220 volts to each two lamps in series, 110 to each lamp as before; the same amount of light is therefore obtained with half the number of mains.

It is found, however, that the amount of copper required for a conductor carrying a current must vary inversely as the square of the E. M. F.; having therefore halved the number of mains, the current carried by the reduced number has double the E. M. F., and the resistance of each two lamps in series being four times that of each two in parallel, only one-fourth the current is required in the mains; the whole amount of copper must therefore be reduced to one-fourth the original amount; which gives each of the two mains half the cross-section of each of the four original mains, the length remaining the same.

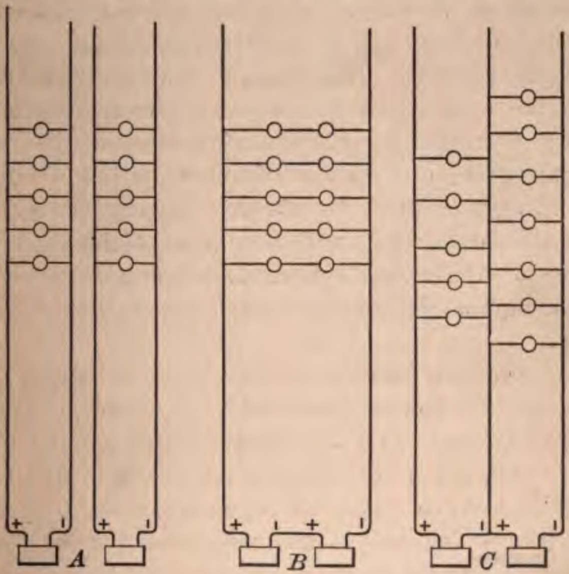

Fig. 101.

But as there are the disadvantages already mentioned in a series connection of incandescent lamps, and as the number of lamps required, or in use simultaneously, is liable to vary on opposite sides of an installation, a third wire is inserted, as shown at *C*. Each lamp has now the same advantages of independent connection with the dynamo, as in the two-wire system, shown at *A*. If an equal number of lamps are burning simultaneously in each row, the current will flow through the parallel branches from one dynamo to the other, as at *B*, the central wire remaining neutral; but if the number is varied by the extinguishing of lamps or otherwise, the third wire furnishes a path for the surplus current required by the row having the greater number lighted, which will flow to that side in consequence of the reduced resistance resulting from the greater number of branches open through the lighted lamps.

We have now three mains at *C*, each half the size of each of the four mains at *A*; the whole amount of copper required at *C* is therefore only three-eighths of that required at *A* to accomplish the same result. It is found, however, that the third, or neutral wire, as it is termed, can be of reduced diameter, by which in practice a further reduction of about $4\,{}^1/_2$ per cent in the total amount of copper is effected.

The feeding mains, on which no lamps are placed, extend as directly as possible from the central station to a central point in each lamp district, and are there connected with the lamp mains, whose size for different sections is made proportional to the number of lamps; and these are tapped, as in other systems, at the various *points* where lamps are required, and connected with mains which extend into the buildings; all the mains being constructed on the three-wire system.

For underground conduits, iron pipes are used in this system, prepared in sections of convenient length, inclosing the three wires imbedded in a compact insulating compound of asphalt and petroleum, pumped in while hot; the wires being separated from the pipe and from each other by rope wound with space between the turns for the passage of the liquid, which solidifies at 330° F.; solid copper rods being preferred to cables.

THE STORAGE BATTERY SYSTEM. — The storage battery has recently become an important auxiliary in electric lighting in connection with the incandescent direct current system.

Every installation must be equipped for its maximum requirement of light, which varies greatly at different hours and at different seasons; the supply required from 6 to 11 P.M. being far in excess of that required during any other part of the twenty-four hours, and that required for the long nights of the cold season exceeding that for the short nights of the warm season.

To meet this maximum demand with a full supply of generators and power, requires a large investment of capital, especially for large central stations in cities, a considerable part of which is unemployed three-fourths of the time, entailing heavy expense for interest which must be added to the cost of the light furnished. This investment of unemployed capital can be reduced to the minimum by the use of storage batteries, as the supply of generators and power can then be made proportional to the average daily amount of light required during the cold season instead of the maximum amount, and the generators run to their full capacity both day and night; the surplus electricity, generated during the daily minimum requirement of light, being stored in the batteries to meet the daily maximum requirement.

The electricity furnished by the battery has a very important advantage for lighting over that furnished direct from the dynamo, the supply being absolutely steady, while that from the dynamo is subject to the fluctuations incident to the slipping of the belt, irregularity in the running of the engine, and sparking at the brushes, causing a certain amount of flicker in the light, which, even with the best regulation, can not be entirely eliminated.

For lighting railroad cars the storage battery has proved very successful; a charged battery placed on the train furnishes the light required for a run of a thousand miles, while batteries at the terminal or way stations are meantime being charged, to be exchanged, on the arrival of the train, for those discharged, which in their turn are recharged for the next train.

It is also successfully employed for such special lighting as is often required at theaters, art exhibitions, or private entertainments; and, to a limited extent, for lighting private residences, though too costly to come into general use for this purpose.

THE INDUCED ALTERNATING CURRENT SYSTEM.— Since the amount of copper required to carry an electric current varies inversely as the square of the E. M. F., if a 1,000 or a 1,200 volt dynamo could be substituted for one of 100 or 110 volts, the E. M. F. being multiplied by ten, the amount of copper required for the mains would be inversely, as the square of *ten*, equal to one hundred; mains, therefore, of one hundredth part the weight, could be employed. In the direct current system, however, with single lamps arranged in parallel, this would be impractical, 100 to 110 volt dynamos being the usual size practically admissible. But in the alternating current, induction system, dynamos of even greater E. M. F. can be successfully employed, though 1,000 volts represents the usual standard size. With such dynamos, and lamps at an average distance of a mile from the station, No. 1 B. & S. wire — about $^3/_{10}$ inch diameter — is employed for the feeding mains. This is regarded as a practical, economical basis on which to maintain equilibrium between cost of power at the station and of copper in the mains; if, however, it is found desirable to bring the current a distance of several miles, from some point where power is cheap and abundant, as in the case of water-power, so that economy of copper is more of an object than economy of power, dynamos of greater E. M. F. can be employed, and mains of reduced size; No. 5 B. & S. wire — $^3/_{16}$ inch diameter — being often employed for such installations.

This system, therefore, gives, for city lighting, the advantage of a cheap location in the suburbs for the dynamo and power station, from which distribution can be economically made to where property is more expensive; or for conveying the current cheaply from some point where water power is available; also for cheap distribution in sparsely settled districts. The converters, described in Chapter III., pages 55–60, are placed at the various points where lamps are required, and the small, primary, high potential current is, by this means, converted into a large, induced, low potential current proportioned to the number of lamps required at each point; the alternating current rendering such transformation possible, which would not be possible with the direct current.

The English electricians, Gaulard and Gibbs, first brought this system to public notice in 1883. They adopted the series method of distribution shown in Fig. 102, the converters being placed in series on the primary, high potential mains, and the lamps grouped in parallel on the secondary, induced current mains connected with each converter, as shown, but insulated from the primary mains. While constancy of current at the several groups could easily be maintained in this system by dynamo regulation, as on arc-light circuits, it was found exceedingly difficult to maintain the specific regulation required for constancy of potential at the lamps, as already explained in similar serial grouping in the direct current system; the difficulty here being increased and complicated by the converters. *Hence*, this method, after many efforts to improve it,

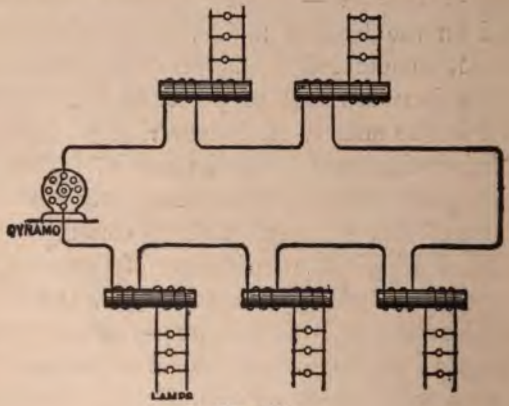

Fig. 102.

was abandoned, and the parallel method, both for the primary and secondary mains, adopted.

In this method, illustrated by Fig. 103, each converter being connected with the primary circuit in parallel, each group of lamps connected with it on the secondary circuit has the same independence of the other groups, as each single lamp in the multiple arc installation shown in Fig. 98; each lamp in like manner being connected in parallel with each secondary circuit as shown.

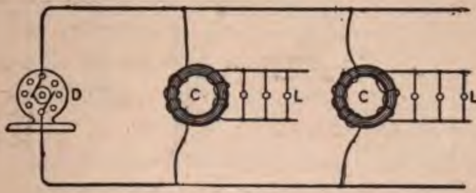

Fig. 103.

Fig. 104 shows an air line installation with its connections in full. The primary mains L^1, L^2, extending from the station, are supported on insulators on the upper cross-arms of the poles P^1, P^2, P^3, while the secondary mains are similarly supported on the lower cross-arms; the converters C^1, C^2, C^3, being placed between the cross-arms, and their primary coils connected above to the primary mains, while their secondary coils are connected below to the secondary mains by short wires as indicated. Branch circuits, l^1, l^2, extend from the secondary mains into the buildings to supply the lamps d^1, d^2. The converters, as mentioned, vary in size, and are estimated by the number of lamps for which each is constructed to supply current; 10 to 80 **lamps** being the extremes, while the three ordinary sizes most in demand are respectively for 20, 30, and 40, 50-volt, 16 candle-power lamps.

The very best construction and best insulation are exceedingly important in converters, the success of the system depending largely on their quality; since in dealing with currents of such high E. M. F. the failure of insulation may result in the burning out of the converter and its immediate connections.

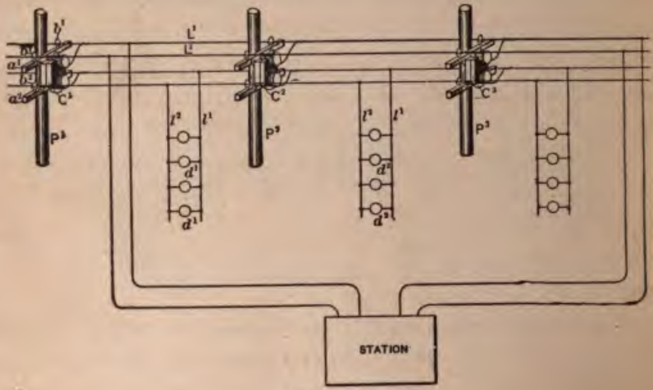

Fig. 104.

In estimating the comparative economy of the alternating and direct current systems, the cost of converters must be added to the alternating current estimate; while on the other hand, the amount of copper required in the alternating current mains being much less than in the direct current mains, and the construction of the dynamo and auxiliary apparatus required at the station being simpler and less expensive, the reduction of expense in these items must be placed as an offset to the expense of converters.

The parallel system of distribution, which has proved to be the practical solution of the problem of distribution by the induced alternating current, was originally suggested by Rankin Kennedy of Glasgow, and, it is claimed, was put in practical operation for the first time by William Stanley at Great Barrington, Mass., in 1885.

The success of this experiment led to the development of the system on a large scale in 1887 by the Westinghouse Electric Company of Pittsburg, Penn., with which Mr. Stanley has been prominently connected, and to whose skill in the construction and perfection of apparatus the success achieved is largely due.

M. M. M. Slattery of Fort Wayne, Ind., who also claims priority for the first practical experiment, should be recognized as one of the successful pioneers of this system; the promotion of the Slattery induction system, which is substantially the same as that here described, being immediately subsequent to that of the Westinghouse system. In England, Kapp and Mackenzie have been its most active promoters.

THE PRIMARY ALTERNATING CURRENT SYSTEM.— Incandescent lighting by the primary alternating current has already been referred to in connection with the Gordon dynamo in Chapter III., pages 46–49; 5,000 twenty candle-power lamps, in multiple series, being illuminated by currents from a single dynamo, taken directly from the coils of its stationary armature; the Swan, 30-ohm lamp, being used. The Gordon system, in use for some time in England, has never been introduced into the United States; and Gordon himself has recently abandoned it for the direct current system.

Within the last five years Charles Heisler of St.

Louis, Mo., has introduced a system based on the primary alternating current method. with series distribution. low resistance, incandescent lamps of 30 candle-power, and a three to four ampere current carried by a No. 8 copper wire. The obvious electrical difficulties involved in such a system Mr. Heisler claims to have successfully overcome; series distribution under these conditions being rendered practical by his short-circuiting device which cuts out the lamp in case a filament breaks, while the low resistance of the lamp filament adapts it to a current of much greater strength than that of the ordinary incandescent lamp, though less than half that of the ordinary arc lamp current; while the large candle-power specially adapts this lamp to the lighting of streets and large buildings. It is claimed that perfect automatic regulation of E. M. F., current and resistance has been attained for every variation of load, from the full capacity of the circuit to that of a single lamp; dispensing not only with the converters required in the induction system, but also with the distributers, resistance boxes, and various safety devices required in other systems. Its principal feature, however, is the great economy of copper by the use of mains adapted to a 4-ampere current as compared with those required for a 200-ampere current.

The Bernstein lamp is preferred both in this and in the induction system on account of its large filament of low resistance.

METERS. — In all the various systems of incandescent lighting by parallel distribution, meters, such as have been described in Chapter VI., pages 150–155, for determining the amount of current consumed, are connected *with the* mains at the various points where lamps are required, each company adopting some special style, and charging its customers in accordance with this measurement.

FUSES. — As electric light wires are liable from accidental causes to become overheated and ignite inflammable matter in close proximity, short fuses of soft metal are placed both in the mains and branch circuits, and wherever groups of lamps, as for chandeliers, or electroliers, are required. If from any abnormal increase of current the temperature of the conductors approaches an unsafe degree, the fuse melts and opens the circuit; the fuses in the main and branch circuits being adjusted to the requirements of each circuit by difference of size, which produces the difference of resistance necessary for the melting temperature; a small fuse being more easily melted by a current of given strength than a large one. These fuses are attached by binding screws, and are easily replaced by new ones when melted.

SWITCH-BOARDS. — Every station, whether for arc or incandescent lighting, is provided with a switchboard, embracing the terminals of the various circuits properly designated, so that connection between the dynamos and the circuits in a large building, or lamp district, can be instantly opened or closed, and the supply of current thus diminished or increased, according to the number of lamps required at different hours.

Several circuits may extend from the same dynamo, from different dynamos, or from connected dynamos, to the various rooms or floors of a large building, or the various sections of an extended area in a city; all under control of the operator at the station; so that any particular room, floor, or section, can be either connected or cut off by moving a switch.

LIGHTING MINES. — The incandescent system has a very important application in the lighting of mines; the station being located at the mouth of the shaft, and current distributed through the various subterranean passages. This system is especially adapted to coal mines as a protection against the fatal accidents so often resulting from the ignition of inflammable gases; the inclosure of the glowing filament in an air-tight glass bulb affording almost absolute security, since even the accidental breaking of the bulb would shatter and extinguish the filament before the gas could enter. The vitiating of the air by the consumption of oxygen, and the odor of burning oil from numerous lamps, is another evil which is eliminated. These advantages, and the superior illumination afforded, have made the incandescent lamp exceedingly popular with miners, wherever it has been introduced. Portable lamps with battery attachment are also in use among miners.

INSTALLATION RULES. — The following is a brief summary of the rules usually given for the regulation of an electric light installation. 1. The dynamo should have a dry location; should not be exposed to dust or flyings; should be kept clean and well oiled, and its internal insulation should be practically perfect. 2. All conductors in the dynamo room should be properly supported, insulated, numbered, and conveniently arranged for inspection. 3. The construction of switches or commutators for opening or closing circuits, should be such that when moved or left there shall be no liability to heating or the formation of an arc. 4. The gauge of the wire on every part of the circuit should be proportioned to the current, and all junctions between conductors of different size should be fitted with fuses, so that the temperature of a conductor at any point cannot exceed 150° F. 5. All joints should be soldered, or electrically welded, and made mechanically and electrically perfect. 6. Complete metallic circuits should be used, and all connection with gas or water pipes as conductors avoided. 7. Bare wires, passing over buildings, should be at least seven feet from every part of the building; and those crossing thoroughfares should be high enough to allow free passage for all vehicles and fire apparatus. 8. Underground wires should be thoroughly insulated, easily accessible, and their position clearly indicated. 9. The insulation of indoor wires should receive special care, so as to protect the building and its occupants against dangerous currents, and to prevent electric waste, particularly where the wires pass through walls or floors, or in close proximity to metallic masses; and they should be incased in hard insulating material where the ordinary wrapping is liable to abrasion or the depredation of rats and mice; and, when placed beneath floors, they should be protected against mechanical injury and their position clearly indicated. Covered wire should have the preference for indoor work. Frequent electrical testing is exceedingly important, as the only safeguard against waste of current or injury to the conductors or insulation, since the ordinary indications of leakage by smell or otherwise, as in the case of gas or water, are absent. 10. All bare outdoor wire should be thoroughly insulated at its supports, and incased in insulating material for at least two feet on each side. 11. Arc lamps should be provided with globes as a protection against flying sparks from the carbons; and all parts which require handling should be insulated from the circuit.

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